Analysis and Optimization of Medium Voltage Distribution Networks with Integration of Decentralized Generation

Von der Fakultät für Elektrotechnik, Informationstechnik, Physik

der Technischen Universität Carolo-Wilhelmina

zu Braunschweig

zur Erlangung des Würde eines

Doktor-Ingenieurs (Dr.-Ing.)

genehmigte

Dissertation

von

M.Sc. Nasser Gamal Abdel-Latif Hemdan

aus Elminia, Ägypten

eingereicht am:	17.01.2011
mündliche Prüfung am:	28.04.2011
Referenten	Prof. Dr.-Ing. Michael Kurrat
	Prof. Dr.-Ing. habil. Lutz Hofmann
Vorsitzender	Prof. Dr.-Ing. Walter Schumacher

2011

Dedicated to:
My country Egypt, my parents,
my kind wife, my kids (Asmaa – Abdel Rahman – Rawan),
my sisters and my brother

ACKNOLEDGMENT

All deepest thanks are due to Almighty God, the merciful, and the compassionate for uncountable gifts given to me.

First and foremost I want to thank my supervisor Prof. Dr.-Ing. ***Michael Kurrat***. It has been an honor to be one of his Ph.D. students. He has taught me, how good research in electrical energy systems can be done. I appreciate all his contributions of time, ideas, experience productive and stimulating. I want to thank him for the pleasant and trusting co-operation as well as the possibilities to present the results of my work in national and international conferences. I am also thankful for the excellent example he has provided as a successful professor.

I am very grateful to Prof. Dr.-Ing. habil. ***Lutz Hofmann*** and Prof. Dr.-Ing. ***Walter Schumacher*** of the examination committee for devoting some of their time to read and evaluate this study.

I wish to extend my gratitude to the Egyptian Government, Ministry of Higher Education, represented by the cultural affairs and missions sector in the Egyptian Embassy in Berlin for financial support.

Special thanks to Dr.-Ing. ***Ulrich Braunsberger*** for his support in the first steps in my work and my life in Germany. My deep thanks to all my colleagues and the entire staff members of the institute of High Voltage Technology and Electric Power Systems, Technische Universität Braunschweig. Personal thanks count for my working group "Energy Systems" for interesting technical discussions and support. The members of the Energy Systems group have contributed immensely to my personal and professional time at TU Braunschweig. The group has been a source of friendships as well as good advice and collaboration. Special thanks to ***Gunnar Bärwaldt*** for his time in reviewing my papers as well as interesting discussions. Also, I want to thank Dr.-Ing***. Magnus Pielke*** for supporting me in learning NEPLAN software, also for his time to discuss with me different issues related to my work. I would like to thank ***Benjamin Deppe*** who was my office colleague; I really enjoy working with him in a research project. I would like also to thank Mrs. ***Christine Nardmann***, for her support during my work in the institute. I really appreciate her help to finish the official papers also her continuous asking about my family.

I would like to thank Dipl. Ing. ***Volker Schwanitz*** from **EN|BS Braunschweig**, Germany for providing the data concerning integration of decentralized wind power into MV distribution networks. I appreciate his discussions and contributions.

I want to extend my thanks to the staff members of **EWE Oldenburg,** Germany, for providing the required data concerning the optimal switching of MV distribution networks with the existence of decentralized generation. I really appreciate all the contributions and creative discussions during the work in this project.

I would like to thank all my Egyptian friends who are PhD students in TU Braunschweig. I want to thank them for supporting me and my family to enjoy our stay in Braunschweig. Lastly, I would like to thank my family for all their love and encouragement, for my parents who raised me with a love of science and supported me in all my pursuits. I would like also to express my deepest thank and profound gratitude to my kind wife ***Nabila Ali Elmasry*** and my little kids ***Asmaa, Abdel Rahman,*** and ***Rawan*** for their support, patience and encouragement during the course of this study.

Nasser Gamal Abdel-Latif Hemdan

Braunschweig, Germany, in January 2011

KURZFASSUNG

Das Interesse an der Integration Dezentraler Erzeugern (DE) in die Nieder- und Mittelspannungsnetze ist überall auf der Welt größer geworden, weil Wirtschafts- und Umweltfaktoren der DE die Antworten auf Fragen zunehmender Last, Zuverlässigkeit, Verschmutzung und Preis geben sollen. Zur Beantwortung der Fragestellungen muss der Durchdringungsgrad von DE in den in den Verteilungsnetzen analysiert werden. Bei optimaler Einbindung der Dezentralen Erzeugungseinheiten können die Netze angepasst betrieben werden, sodass die Netzbetreiber davon profitieren.

In dieser Dissertation wird eine Analyse und Optimierung der Mittelspannungsverteilungsnetze (MS) in Verbindung mit DE Einheiten durchgeführt. Die präsentierte Arbeit kann hauptsächlich in vier Teile unterteilt werden.

Im ersten Teil werden Untersuchungen zu den Einflüssen der Integration von DE-Einheiten auf die Belastbarkeit von MS-Verteilungsnetzen durchgeführt. Die Belastbarkeitsuntersuchung wird in Bezug auf zwei Aspekte bewertet, den Spannungsgrenzen und der Spannungsstabilität. Der Einfluss der Blindleistungseinspeisung von DE im Hinblick auf die Netzverlusten wird ebenfalls untersucht. Diese Einflüsse werden anhand von zwei radialen Verteilungsnetzen bewertet, während die DE an jedem Knoten mit verschiedenen Durchdringungsraden und verschiedenen Leistungseinspeisungen integriert werden. Es wird die Continuation Power Flow Methode (CPF) verwendet, um die Netzbelastbarkeit in Bezug auf die genannten Aspekte zu bewerten. Der Einfluss der Position und die Größe des DE auf die Spannungsstabilitäteines dritten Netzes wird basierend auf einem Spannungsstabilitätsindex bewertet.

Für den zweiten Teil dieser Arbeit wird eine Methode der Optimierung dargestellt, die die Integration von dezentralen Erzeugern beschreibt, ohne die zulässigen Spannungsgrenzen zu verletzen. Es wird eine Methodik vorgeschlagen, die auf dem Konzept der CPF beruht. Die Wirksamkeit der präsentierten Methodik konnte in einem Test Netz durch die Integration von verschiedenen Durchdringungsgraden DE demonstriert werden. Es konnte gezeigt werden, dass die Netzverluste minimiert wurden und eine Vergleich Mäßigung der Spannungsprofile erreicht werden konnte.

Im dritten Teil dieser Arbeit, werden Untersuchungen der Dezentralen Wind-Energie-Einspeisungen bezüglich der Spannungsreihen, Spannungsprofile, und Energie-Verluste eines realen MS-Verteilungsnetzes durchgeführt. Es wird die Möglichkeit der Integration einer Windkraftanlage (WKA) in ein bestehendes Netz mit bereits drei WKA basierend auf

den Technischen Anschlussbedingungen des Bundesverbandes der Energie- und Wasserwirtschaft (BDEW) analysiert. Der Simulation werden Standartlastprofile für Haushalte an den Niederspannungsabgängen der MS-Station hinterlegt.

Der optimierte Betrieb der MS-Netze in Verbindung mit den DE wird für typische Netze dargestellt. Die typischen Netze werden basierend auf echten Daten erstellt. Die Zielfunktion dieser Arbeit besteht darin, die Verluste zu minimieren. Aus diesem Grund werden in einem weiteren Teil dieser Arbeit Last- und Erzeugungsprofile eingeführt. Die VDEW Standardlastprofile für Haushalte, und Gewerbe werden in der Netzberechnung verwendet. Der Konfigurationsprozess der Trennstellen (Trennstellenoptimierung) der Netze wird mit Hilfe der NEPLAN-Software durchgeführt. Aufbauend darauf wird, unter Zuhilfenahme einer C++ Routine, eine Netzberechnung Software für die verschiedenen Durchdringungsgrade von 0 %, 50 % sowie 100 % vorgestellt. Weiterhin werden Erzeugungsprofile verschiedener Typen DE (z.B. Photovoltaik und Blockheizkraftwerke) basierend auf Messdaten in die Untersuchung mit einbezogen. Als Ergebnis der Untersuchung konnte eine verminderte Leistungsauslastung, eine Verbesserung der Spannungsqualität sowie eine Minimierung der Energie-Verluste erzielt werden.

ABSTRACT

The interest in integration of Decentralized Generation (DG) at Low and Medium Voltage (MV) distribution networks has been increased all over the world due to economic and environmental factors which drive DG to be the solution of different problems such as increasing of the load demand, reliability, pollution, and energy price. As the penetration level of DG increases, the performance of the distribution grids has to be analyzed to evaluate the different implications of its interconnection. The DG units are needed to be optimally accommodated and operated; therefore the customers and the utility companies achieve more benefits from their integration.

Within the framework of this thesis, an analysis and optimization of MV distribution networks with interconnection of DG units have been introduced. The presented work can be mainly divided into four parts.

In the first part, investigations of the impacts of DG unit's interconnection on the loadability of MV distribution networks are introduced. The loadability is evaluated based on two aspects; namely the maximum loading according to the voltage limit and the maximum loading according to the voltage stability limit. Moreover, the influence of the reactive power injection from DG on the grid losses is also investigated. These impacts are evaluated for two radial distribution networks where the DG is integrated at each node with different penetration levels and different reactive power injections. The Continuation Power Flow (CPF) method is used to assess the loadability with respect to the former two aspects. Furthermore, the influence of the location and size of the DG on the voltage stability of a third network is evaluated based on a previously introduced voltage stability index.

In the second part a new methodology for integration of the DG units in order to enhance the voltage limit loadability (i.e. the maximum loading which can be supplied by the power system while the voltages at all nodes are kept within the limits) is presented. The proposed methodology is based on CPF. The effectiveness of the presented methodology is demonstrated in a test network with integration of different penetration levels of DG. The proposed method yields efficiency in obtaining more benefits from the same amount of DG power, decreasing the losses and improving the voltage profiles.

In the third part, investigations on the implications of Distributed Wind Power Generation (DWPG) on voltage ranges, voltage profiles, and energy losses of a real MV distribution network are introduced. The availability to integrate a new wind mill into the network that already contains three wind mills is examined with respect to the technical conditions for generation connection to the MV networks of the German Association of Energy and Water Industries (Bundesverband der Energie- und Wasserwirtschaft - BDEW). In the simulation we used one year measured wind data and German Association for Electricity standard load profiles (Verband der Elektrizitätswirtschaft - VDEW) of the households, which are connected to the LV side at each MV substation.

In the last part of the thesis, a new methodology for optimal reconfiguration of a typical MV network with the existence of different DG technologies is presented. The proposed methodology implementing C++ and NEPLAN software is developed for optimizing the switching state of the network where the load and generation profiles are taken into consideration. The objective function of the proposed algorithm is minimizing the energy losses. The VDEW standard load profiles for households and commercials are used in the simulation. The supplied power from the DG units is taken with constant penetration levels of 0%, 50%, and 100% in the first phase of the study. Then the generation profiles of different DG types are taken into consideration based on measurement data. The presented method yields good results in minimizing the energy losses, improving the voltage ranges, and relieving the bottlenecks in the lines.

TABLE OF CONTENTS

ACRONYMS

AI	Artificial Intelligence
BDEW	Bundesverband der Energie- und Wasserwirtschaft (German Association of Energy and Water Industries)
BEWAG	Berliner Städische Elektrizitätswerke-Aktiengesellschaft
CHP	Combined Heat and Power
CPF	Continuation Power Flow
DA	Distribution Automation
DG	Decentralized Generation
DR	Distributed Resources
DWPG	Decentralized Wind Power Generation
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Law)
EP	Evolutionary Programming
EPA	Electric Power System Area
FC	Fuel Cell
FS	Fuzzy System
G0-G6	Gewerbebetrieb (Commercials)
GA	Genetic Algorithm
GHG	Green House Gas
GWEA	German Wind Energy Association
GZF	Gelichzeitigkeitsfaktor (Simultaneity Factor SF)
H0	Household
HV	High Voltage
IEEE	Institute of Electrical and Electronics Engineers
ISO	Independent Transmission Operator
L0-L6	Landwirtschaftsbetrieb (Farms)
LMP	Location Margin Pricing
LV	Low voltage
MV	Medium Voltage
OLTC	On Load Tap Changer
PCC	Point of Common Connection
PL	Penetration Level
PQ	Active-Reactive power
PSAT	Power System Analysis Toolbox
PV	Photovoltaic
RESA	Renewable Energy Sources Act
RTO	Regional Transmission Operator

SA	Spring-Autumn
SA	Simulating Annealing
Su	Summer
T&D	Transmission and Distribution
TS	Tabu Search
VDEW	Verband der Elektrizitätswirtschaft (German Association for Electricity)
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
VLL	Voltage Limit Loadability
VSLL	Voltage Stability Limit Loadability
Wi	Winter
WKO	Wirtschaftskammer Österreich (Commerce Austria)
WT	Wind Turbine
WTG	Wind Turbine Generator

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

The electrical energy sector is facing substantial changes worldwide. This phase is characterized by a dramatically increase in the electrical energy consumption especially in emerging countries. Recently a top priority is given to develop a reliable, sustainable, environment friendly as well as low-cost electrical energy supply. This includes a sensible energy mix and improvements in efficiency of energy generation, transmission and consumption [Weber et al.,2009]. As a number of events that have been brought to the fore the vulnerability of the current centralized electrical energy supply infrastructure, such as terrorist threats, natural disasters, geopolitical disruptions, ageing of a highly complex infrastructure, climate change and regulatory and economic risks [Bouffard et al.,2008], DG appears to be one of the key answers for different problems.

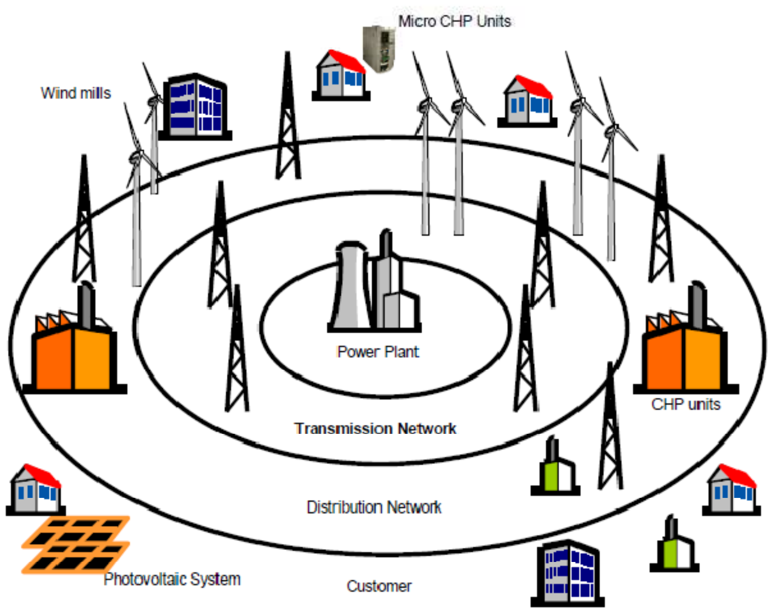

Figure 1 - 1: Structure of the future energy supply [Pielke et al.,2008]

In the decentralized system, the electrical power supply will be transferred from a vertical one to a horizontal system as indicated in Fig. 1-1. In the traditional system the electric power industry has been driven by a paradigm where most of the electricity is generated in large power plants, sent to the consumption areas through HV transmission lines, and delivered to the consumers through a passive distribution infrastructure that involves HV, MV and LV networks. In this paradigm power flows only in one direction: from the power station to the network and to the consumer [Lund et al.,2003]:

Paradigm 1:

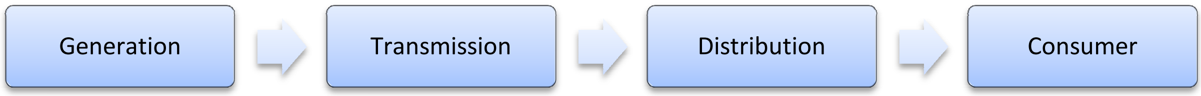

Figure 1 - 2: Vertical power system

Due to a large scale integration of DG to either the MV or the LV levels the above paradigm will be changed to paradigm 2.

Paradigm 2:

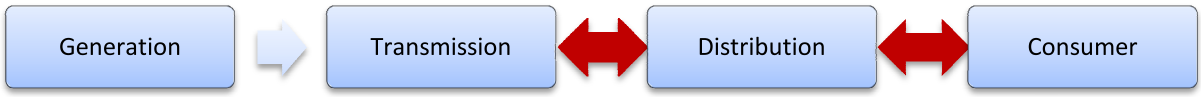

Figure 1 - 3: Horizontal power system

The DG term is used to describe small-scale power generation which is located on the distribution system close to the point of consumption. Such generators may be owned by a utility or more likely by a customer who may use all of the generated power on site or sell a portion or perhaps all of it to the local utility [Masters,2004]. DG technologies include small combustion turbine generators (including micro turbines), internal combustion reciprocating engines and generators, photovoltaic panels, and fuel cells. Other technologies including solar thermal conversion, stirling engines, wind power generation and biomass conversion are considered as DG [Mount,2003].

When the penetration of DG is high, the generated power of DG units not only alters the power flow in the distribution network, but in the transmission network as well. As a consequence, the connection of DG to the grid may have significant implications on different technical issues, e.g. voltage profiles [Repo et al.,2003;Sun et al.,2009], voltage quality [Deng et al.,2008;Morsi et al.,2008], Losses [Ayres et al.,2009;González-Longatt,2007], stability [Calderaro et al.,2009;Chen,2008], etc. Different impacts of interconnection of DG units can be seen in Fig. 1-4 [Ault et al.,2000].

In spite of the benefits of utilizing DG units within the power systems, such as the increase of the system efficiency and the improvements in the power quality and reliability, many technical and operational challenges have to be resolved before DG becomes commonplace [Azmy,2005;El-Khattam et al.,2004]. More analyses of the impacts of the integration of DG units into MV distribution networks are needed. Moreover, these analyses have to be done in more details with respect to the generation types. Optimization of the MV distribution networks with a large penetration of DG is also needed; therefore the utilities can get more benefits.

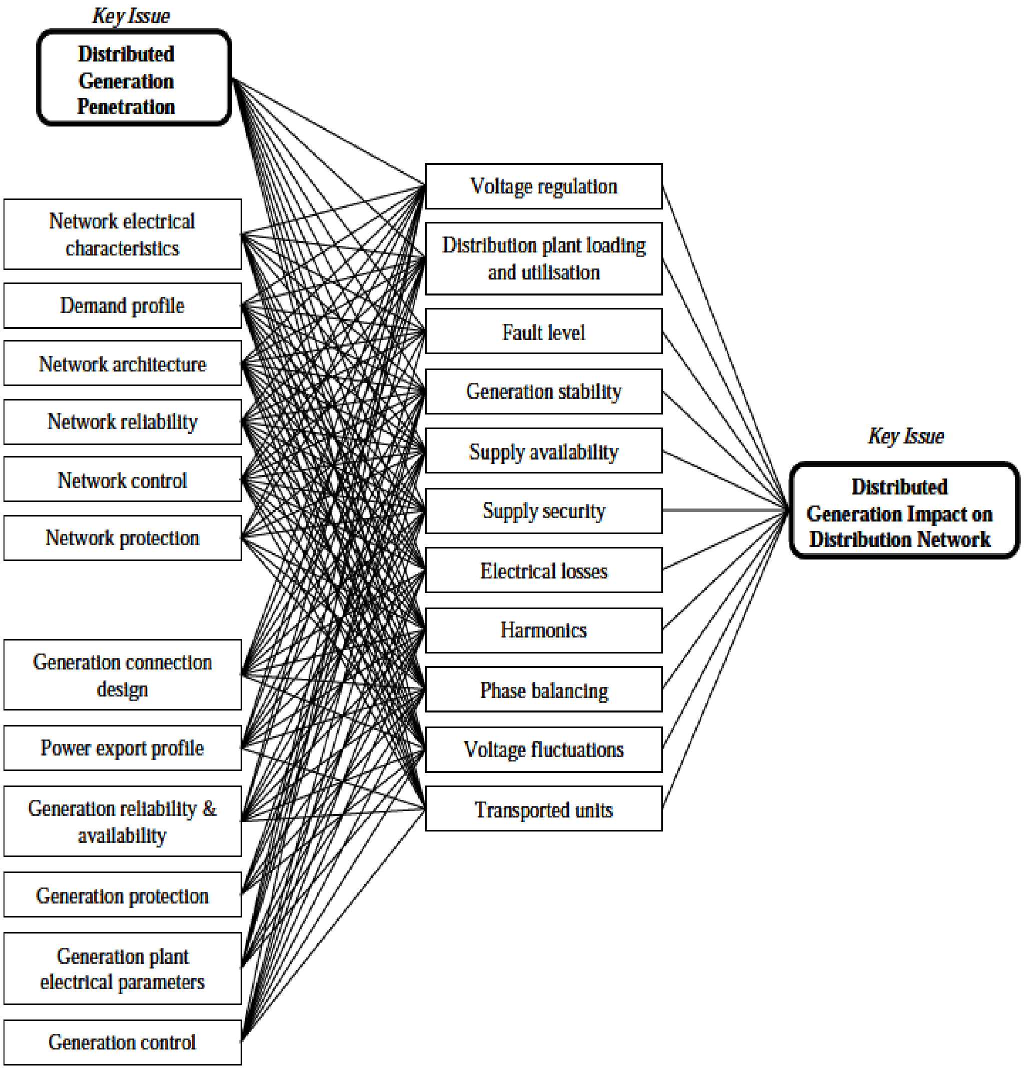

Figure 1 - 4: Impacts of DG on distribution networks [Ault et al.,2000]

1.1 Objectives and Approaches

The main objectives addressed by the current study are to evaluate the influences of interconnection of DG units into balanced 3-phase MV distribution grids. Moreover, define an algorithm for efficient integration of DG units into distribution networks for improving the normal operation loadability. Finally optimize of MV networks with a large penetration level of DG through network reconfiguration. To fulfill these objectives, the research approach consists of four tasks:

- ***Investigations on the impacts of DG on the voltage stability and voltage limit loadability of MV distribution networks:***

The voltage stability of a 69 node distribution network is evaluated using a previously introduced voltage stability index with integration of different DG powers at different locations. Then, two different loadability aspects of two different MV distribution networks are assessed using CPF method. These networks are investigated with the integration of DG units at each node with different penetration levels and different reactive power injections. The impact of the DG reactive power on the network active and reactive power losses are also evaluated. The Power System Analysis Toolbox (PSAT) was employed in this phase.

- ***Developing an algorithm for optimal accommodation of DG units in MV distribution networks:***

A new algorithm for accommodating the DG units for enhancing the normal operation loadability of MV distribution networks is developed. The main idea behind the proposed method is to identify different recommended locations for integration different number of DG units into the network. The proposed algorithm was tested on a network of 85 nodes.

- ***Verification on the implications of DWPG on a real MV distribution network:***

An implementation of NEPLAN software to assess the influences of integration of DWPG into a real MV distribution network is performed. The VDEW standard load profiles are used for the households which are connected to each MV station. Measured generation data for three wind generators are used in the simulation. Developing of a new relation based on measured data to evaluate the maximum power at each MV substation is performed. The availability to interconnect a new wind mill into the network is tested based on the specifications presented by BDEW.

- ***Reconfiguration optimization of MV distribution network with the existence of DG units***

Reconfiguration of distribution networks with high penetration levels of DG units based on NEPLAN in combination with C++ to minimize energy losses is performed. The optimization process takes the load and generation profiles into consideration. The presented methodology is applied on a typical network which is built based on a real data.

1.2 Impacts of the Approaches

The study introduces different approaches for analyzing the implications of DG interconnection into balanced 3-phase MV distribution networks. Moreover, optimization of the distribution networks with DG units is presented. Therefore this study will contribute to the following aspects:

- More understanding of the influences of DG units on MV distribution networks.
- Highlighting on the benefits which can be obtained from properly accommodated DG units.

- Incentives for the energy sectors especially in the developing countries to integrate DG units into distribution networks as a part of the solution of the increasing in the load demand.
- Providing of different aspects regarding planning distribution networks with DG units based on measured data.
- Introducing an overview about the reconfiguration of distribution networks with the existence of dispatchable and non-dispatchable DG units

1.3 Thesis Outline

The current thesis is divided into seven chapters. The following are brief descriptions of the content of each chapter:

Chapter 1: Introduction to the study.

Chapter 2: presents an overview about DG units and its integration.

Chapter 3: introduces the implementation of a voltage stability index and CPF method for evaluating the impacts of DG integration on voltage stability and voltage limit loadability of MV distribution networks.

Chapter 4: presents a new algorithm for accommodating DG units into distribution networks for enhancing the normal operation loadability.

Chapter 5: Evaluation of the influences of interconnection of DWPG into a real MV distribution network is presented in this chapter.

Chapter 6: Reconfiguration of a typical network for minimizing the energy loss is introduced in this chapter.

Chapter 7: Summarizes the main conclusions and the future directions.

CHAPTER 2: DECENTRALIZED GENERATION: AN OVERVIEW

Decentralized Generation is not a new phenomenon in the power industry sector but it is an emerging approach for providing electrical energy in the heart of the power supplying system. It mainly depends upon the interconnection and operation of a portfolio of small size, compact, and clean electric power generating units at or near the end user [El-Khattam et al.,2004]. DG has the potential to reduce the air pollution; supply reliable electrical energy to the customers and reduce the cost of energy if its integration is adopted by the power industry, environmental community, end-users and regulators [Greene et al.,2000].

2.1 DG Definition

There are several terms which are used to identify DG, for example *dispersed generation* which is used in North America, *embedded generation* which is used in South American countries*, decentralized generation* which is used in Europe and some Asian countries. It is more common to use *distributed generation* term for all power industry professionals worldwide [Ackermann et al.,2000;El-Khattam et al.,2004].

Some general definitions can be used to clarify the term DG such as: a system where electric power is generated at various locations near the point of use (as opposed to at a central power generating facility) [NYSERDA Website] or as an approach that employs small-scale technologies to produce electricity close to the end users of power [DGEM Website,2010]. IEEE defines DG as an electric generation facilities connected to an Area Electric Power System (EPA) through a Point of Common Connection (PCC); a subset of Distributed Resources (DR). DR is defined as sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies [IEEE,2003]. Moreover, a general definition for DG is provided in [Ackermann et al.,2000] after discussing different issues related to DG definition such as location, purpose, rating, power delivery area, environmental impact, mode of operation, penetration of DG, and ownership. DG was generally defined in [Ackermann et al.,2000] as an electric power source connected directly to the distribution network or on the customer side of the meter. This definition is favorable, even though it is rather broad. Indeed, it puts no limit on the technology or capacity of the potential DG application [Pepermans et al.,2005].

According to the [CIRED,1999] some countries define DG based on the voltage level, while other countries start from the principle that DG is connected to circuits from which consumer loads are supplied directly. Other countries define DG as the generation unit which has some basic characteristic for example using renewable, cogeneration, or being non-dispatched [Pepermans et al.,2005].

2.1.1 DG rating

Regarding to the rating of DG units, there are different definitions for the generation size range according to some institutes and literatures as can be seen in Fig. 2-1 [Ackermann et al.,2000;El-Khattam et al.,2004]. However, the rating definitions of DG units are also depending on the governmental legislation. Two examples are given as follows:

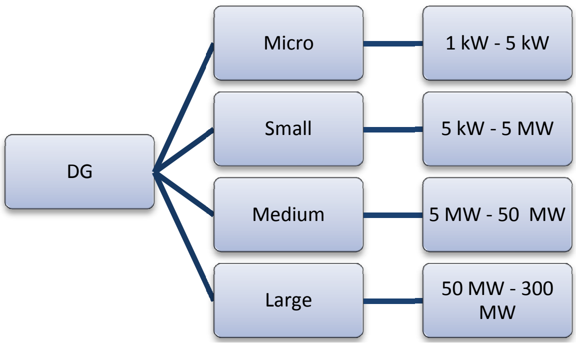

Figure 2 - 1: DG capacities [Ackermann et al.,2000;El-Khattam et al.,2004]

- ***Sweden***

The DG is defined as the generation unit up to 1500 kW. However, using this value alone can't decide that a certain generation unit is a DG or not. For example a wind farm consists of one hundred 1.5 MW wind generators will be considered as a DG units, while the capacity of each unit not the total capacity is relevant to the Swedish legislation. On the other side, for a hydro power station the total capacity is relevant to that law, so in most cases they will not be considered to be as a DG [Ackermann et al.,2000].

- ***Germany***

The local utility BEWAG (Berliner Städtisches Elektrizitätswerk Aktiengesellschaft) which became VATTENFALL has built a power generation station in the city centre. This power station, which feeds into 110 and 33kV distribution lines, provides electricity and heat (300 MW each, respectively). The generated electricity and heat are consumed locally so that this power station can be considered as a DG. It is worth to be mentioned here that this case is certainly a very special case [Ackermann et al.,2000;El-Khattam et al.,2004].

2.2 DG Benefits

Invaluable benefits can be drawn through the interconnection of DG units into electric power networks. An overview on these benefits can be seen in Fig. 2-2. The benefits of DG can be broken as follows:

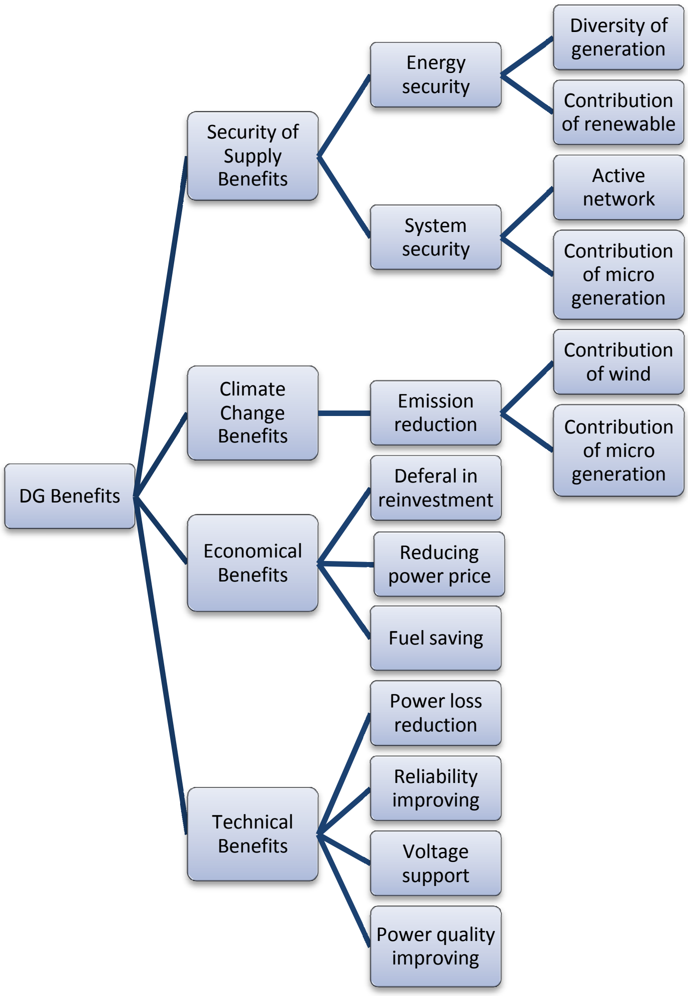

Figure 2 - 2: DG Benefits (based on [Azmy,2005;Smart et al.,2006])

2.2.1 Economical benefits

By integrating the DG units closer to the customer, a potential for avoidance or deferral of the need for building new T&D lines, upgrade the existing power supply system and reduce T&D capacity during network planning can be exist. Thus, DG can be a least-cost planning alternative [El-Khattam et al.,2004;Meyers et al.,2001;OOCC Website,2010;Smart et al.,2006].

Some economical benefits of DG can be discussed as follows:

- DGs can be assembled easily anywhere as modules which have different advantages as they can be installed in a very short period at any location. Each module can be operated immediately and separately after its installation independent of other modules arrival and not affected by other module operation failure.

- Total capacity of DG can be increased or decreased by adding or removing more modules, respectively.
- DGs are not restricted by the centralization of the power as they can be placed anywhere. Thus, DG location flexibility has a great effect on energy prices. However, renewable DGs technology such as hydro, wind, and solar units require certain geographical conditions.
- DGs are well sized to be installed in small increments to provide the exact required customer load demand.
- Some DG technologies provide cogeneration possibilities, which allow site recovery of heat and / or hot water. This has the potential to rise up the energy efficiency to around 90%. In rural villages, the recovered heat can be used for hot water, space heating, industrial processes and even space cooling.
- DGs can reduce the wholesale power price by supplying power to the grid, which leads to reduction of the demand required.
- Due to deregulation DG will have a great importance in generating power locally especially if the location margin pricing (LMP) is applied for independent transmission operators (ISO's) and regional transmission organizations (RTO's). LMP can give an indication of where DG should be installed.
- DG increase the system equipments lifetimes and provide fuel savings.
- Installing DG reduce the construction schedules of developing plants. Hence, the system can track and follow the market's fluctuations and/or the peak-load- demand growth.
- Depending on the nature of fuel used, electricity prices are often lower than power from central plants.
- General uncertainty in electricity markets favors small generation schemes. One of the acknowledged consequences of the introduction of competition and choice in electricity is the increased risk faced by all players in the electricity supply chain from generators through transmission and distribution businesses to retailers. It is well known that the capital outlay required to establish new power stations can be very high.
- DG helps to resolve load pocket problems when load grows but transmission lines cannot feasibly be added. DGs benefits are maximized when DG is located in congested areas to relieve congestion.
- DG decreases the overall costs of producing and delivering power and promotes the development and wider use of renewable energy, which can improve the environment and offers new jobs.

2.2.2 Technical benefits

DG can provide different technical benefits based on different factors, e.g. location and technology. The following are some of the technical benefits [Azmy,2005;El-Khattam et al.,2004;Meyers et al.,2001]:

- Improving availability and reliability of the power supplying network,
- Voltage support and improved power quality,
- Power-loss reduction,
- Reduce power flow inside the transmission network to fit certain constraints and improve its voltage profile,
- DGs can help in “peak load shaving” and load management programs,
- DGs capacities vary from micro to large size so they can be installed on medium and/or low voltage distribution network which give flexibility for sizing and sitting of DGs into the distribution network,
- Other benefits of DG include providing ancillary services, and adding self-generation to customer options,
- DG could prove invaluable for developing countries. Thus, micro power is an attractive option for those countries. DG such as grid-free renewable may be particularly suitable for remote areas.

2.2.3 Environmental benefits

Electric power generation is responsible for about 40% of carbon dioxide emissions, a primary contributor to climate change. In principle, we now have the chance to modify not only the way we supply power but also, at least in significant part, the way we humans successfully restore our and the other critters’ environment [Meyers et al.,2001;Petrie et al.,2001].

Recent DG technologies offer an environmentally source of electrical energy through limiting the Green House Gas (GHG) emissions. By 2050 a widespread installation of micro generation could reduce the household carbon emissions by approximately 15% [Smart et al.,2006]. Also, avoidance of the construction of new transmission circuits and large generating plants are also important environmental benefits.

2.2.4 Supply security benefits

DG can provide additional benefits regarding the security of supply which can be divided into two categories, energy security and system security. The term security of supply can be briefly described as the provision of an electricity supply that is continuous and of a defined quality (in terms of voltage and frequency) [Smart et al.,2006].

By introducing a higher number of smaller generators into the generation mix, the significance of individual larger power stations to security of supply is reduced and the ability of system operators to avoid system wide black out in the face of the loss of a number of generators should be enhanced. All varieties of renewable energy offer positive benefits to security of supply in this case they do not rely on imported primary fuel. An active distribution system should increase security of supply to local loads. Micro generation and micro CHP in particular can reduce peak demand and can therefore reduce the overall stress on the transmission and distribution systems. In this way, micro generation can contribute towards security of supply.

2.3 DG Technologies

In the literatures the researchers classifying the DG technologies and types based on different related issues, such as generation type, energy source, fuel type, combustion, and generation model. These issues and their related DG can be seen in Fig. 2-3 [El-Khattam et al.,2004;Foote,2000;Koeppel,2003;Petrie et al.,2001;RDC,2001;Smart et al.,2006;Thong et al.,2006;Zareipour et al.,2004]. Some DG technologies will be briefly discussed as follows:

- ***Reciprocating engines***

Reciprocating engines are ones in which pistons move back and forth in cylinders. Reciprocating engines are a subset of internal combustion engines, which also include rotary engines. Smaller engines are primarily designed for transportation and can be converted to power generation with little modification. For DG applications, reciprocating engines offer low costs and good efficiency, but the maintenance requirements are high, and diesel-fueled units have high emissions [RDC,2001].

- ***Micro turbines***

Simple micro turbines consist of a compressor, combustor, turbine and generator. The compressors and turbines are typically radial-flow designs, and resemble automotive engine turbochargers. Most designs are single-shaft and use a high-speed permanent magnet generator producing variable voltage, variable frequency alternating current (AC) power. An inverter is employed to produce 50 or 60 Hz AC power. Most micro turbine units are currently designed for continuous-duty operation and are recuperated to obtain higher electric efficiencies [RDC,2001].

- ***Fuel Cell***

Fuel cells (FC) are systems where electricity and heat are generated by electrochemical combination of hydrogen and oxygen where water is generated as a ’waste’ product. The FC thus is a system capable of producing electricity without any mechanical process, resulting in higher efficiencies than regular thermo-mechanical systems and quieter operation [Koeppel,2003].

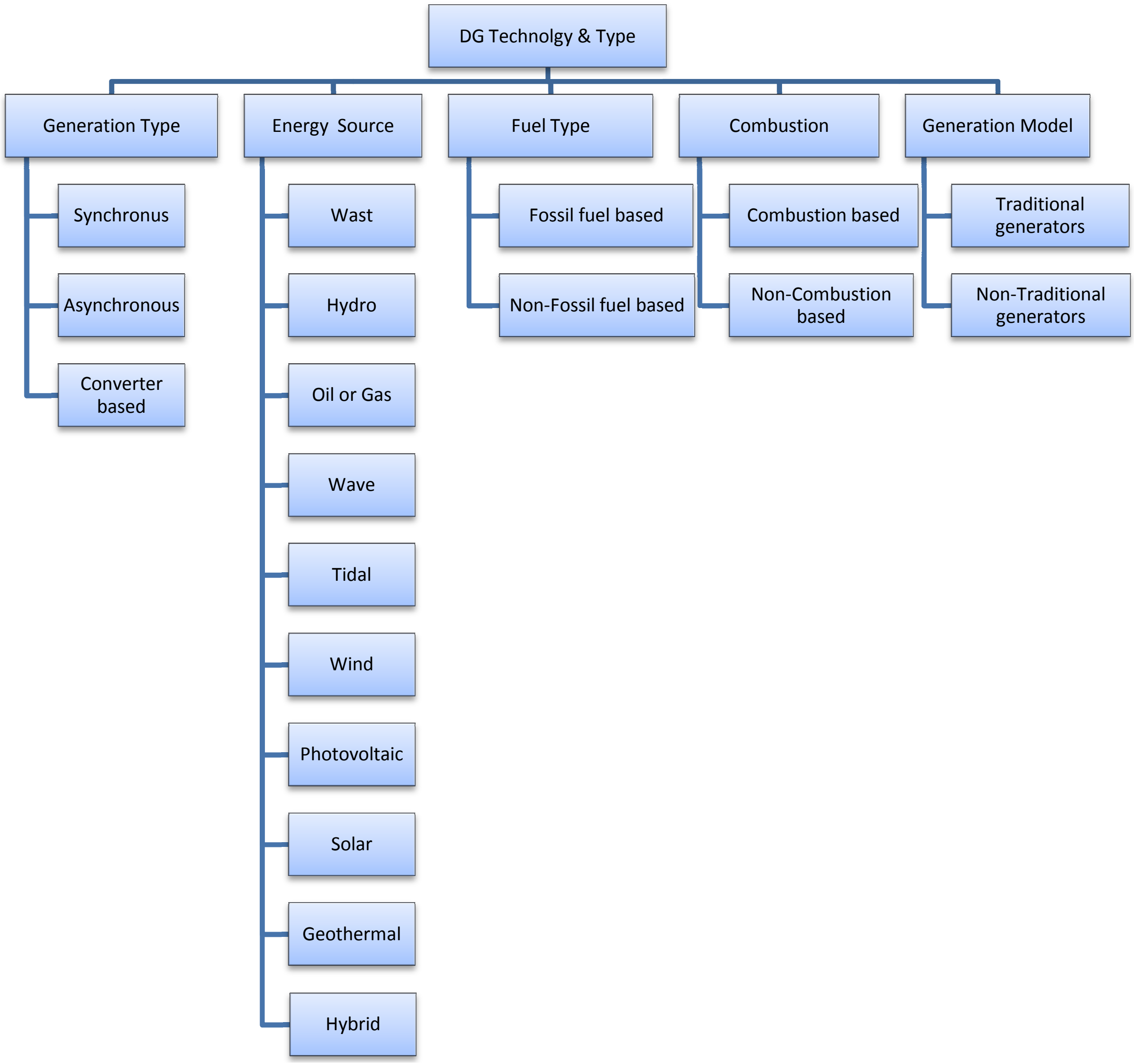

Figure 2 - 3: DG technologies and types classifications

- ***Photovoltaic***

Photovoltaic (PV) is a technology converting solar radiation into electrical energy. PV cell consists of two or more thin layers of semi-conductor material, mostly commonly silicon. When the silicon is exposed to light afterwards electrical charges are generated as a direct current. PV equipment has no moving parts and as a result requires minimal maintenance. It generates electricity without producing emissions of GHG [Thong et al.,2006].

- ***Wind turbine***

Wind energy is not a new form; it has been used for decades. A Wind Turbine (WT) consists of a rotor, turbine blades, generator, drive or coupling device, shaft, and the nacelle (the turbine head) that contains the gearbox and the generator drive. Modern wind turbines can provide clean electricity as individuals or as wind farms [El-Khattam et al.,2004].

2.4 DG Applications

There are many different potential applications of DG technologies; for example some customers use DG to reduce demand charges imposed by their electric utility, while others use it to provide primary a power or reduce environmental emissions. DG can also be used by electric utilities to enhance their distribution systems. Many other applications are existing for DG solutions. Figure 2-4 shows a list of those of potential interest to electric utilities and their customers [El-Khattam et al.,2004;Hemdan et al.,2009;Konstantinos,2004;RDC,2001]. A brief discussion on each application is given in the next subsections.

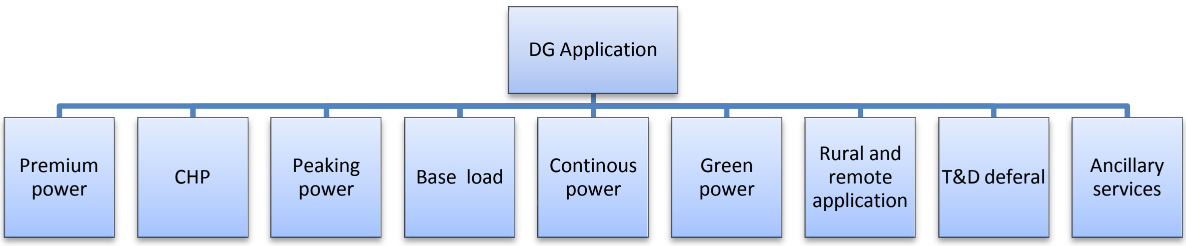

Figure 2 - 4: DG applications

- ***Premium power***

In this application the DG unit is used to provide electrical energy supplying at a higher level of reliability and/or power quality than this provided from the distribution network. Customers typically demand uninterrupted power for a variety of applications, and for this reason, premium power is sorted into three further categories[RDC,2001]:

- Emergency power system
- Standby system
- True premium system

- ***Combined heat and power (CHP)***

Combined Heat and Power also knows as cogeneration, utilizes the wasted exhaust heat as a useful thermal output, typically steam. The steam may be used either for building heating or cooling [DG Website,2010]. The CHP fuel is gas or oil and the whole efficiency of the system is increased through the utilization of the heat. In the next decade there will be CHP micro units with FC technology. The power output and the whole efficiency are the same but the advantages of this technology are the higher electrical efficiency and the higher efficiency in part load. Furthermore, the FCs can use hydrogen directly in a future hydrogen system [Schulz et al.,2006].

- ***Peaking power***

In a peaking power application, DG is operated between 200-3000 hours per year to reduce the overall electricity costs. It is operated to limit the power peak in the network and in this case the DG application can be called peak shaving. Therefore, DG units will be operated to reduce the utility’s demand charges, to defer buying electricity during high-price periods, or to be allowed for lower rates from power providers by smoothing site demand [Pielke et al.,2007;RDC,2001].

- ***Base load***

In this application, the DG unit will be usually owned by the utility. The DG will provide a part of the required power. Moreover, it will be used to support the distribution network by improving the voltage profiles and decreasing the power loss and enhancing the power quality [El-Khattam et al.,2004].

- ***Continuous power***

Continuous generation applications produce power on a nearly continuous basis, running at least 6,000 hours per year. When evaluating the usage of DG technologies in this capacity, customers consider competing grid price, as well as the installed cost of the unit and fuel costs. [DG Website,2010].

- ***Green power***

In this application the renewable energy, such as wind, PV, geothermal, wave and tidal, hydro, and bio waste will be utilized in DG form. Therefore, DG will provide a reduction in the emission of GHGs in particular of carbon dioxide.

- ***Rural and remote application***

Many rural areas are too remote or very poor to support energy systems that are connected to the electricity grid. In this case DG units are implemented to provide electrical energy to these areas [Petrie et al.,2001].

- ***T&D deferral***

As the investments in electrical T&D are faced by economical and environmental problems, DG is integrated to postpone or avoid T&D expansions. In this application DG need to be interconnected at a strategic location to achieve these objectives.

- ***Ancillary services***

The DG units can be integrated for providing ancillary services such as frequency regulation, voltage control, standby reserve, back-up reserve, load following, loss compensation, black-start capability, reactive power service.

2.4.1 Utilization of different DG technologies in different applications

It can be concluded from the discussion of the previous sections that not all DG technologies can be implemented in all applications. Table 2-1 cites the way different DG technologies are fit or not to be utilized for a certain application [DG Website,2010;El-Khattam et al.,2004;Joos et al.,2000;Konstantinos,2004;RDC,2001].

Table 2 - 1: Utilization of DG in different applications

		DG Technology				
		Dispatchable DG			Non-dispatchable DG	
		Micro Turbine	Fuel Cell	Reciprocating Engines	PV	Wind
Application	**Continuous**	M	G	G	M	P
	CHP	M	M	M	P	P
	Peaking	M	P	G	P	P
	Base load	G	G	G	P	P
	Green	P	G	P	G	G
	Premium	M	G	M	P	P
	Ancillary services	G	G	G	M	M
	T&D deferral	M	M	G	M	M
	Rural & Remote supply	M	G	G	M	M

Key: G – *Good fit*, M – *Moderate fit*, P – *Poor fit*

2.4.2 Dispatchable versus non-dispatchable DG

As indicated in Table 2-1, the dispatchable DG units can be utilized mainly in the applications such as base load, continuous, peaking and premium while non-dispatchable DG units cannot be utilized in these applications. For example, in the case of CHP units the DG can be operated to follow the electrical or the thermal load and in this case the network operator can use them for providing more benefits. In the other side integration of non-dispatchable DG units can raise different problems such as the frequency control in the case of the presence of wind generators. In the future different concepts based on new communication technologies can provide dispatching of different small DG units in order to obtain different benefits and overcome problems such as increasing the loss, voltage fluctuations, and impacts on the frequency control.

2.5 DG Impacts on Distribution Networks

As the penetration of DG into the grid is high, the supplied power from DG units will not only affect the power flow in the distribution network, but also the transmission network. Therefore the interconnection of DG to the grid may have different implications on the distribution network [Hemdan et al.,2009;Thong et al.,2004b]. In this section, different impacts (see Fig. 2-5) of DG integration on power distribution network will be discussed.

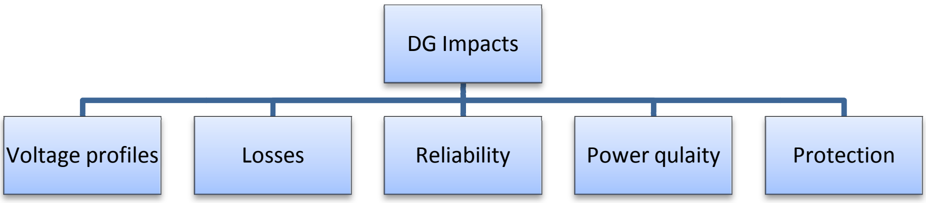

Figure 2 - 5: DG impacts on distribution networks

2.5.1 Voltage profiles

Voltage profile is extremely important for the end users because it's a basic demand for electrical equipments running near the rated voltage. DG can provide voltage support to raise the voltage at the end of the feeder [Sun et al.,2009]. The impact of DG on the voltage profile can be positive or negative depending mainly on the type of DG, amount of power DG supplies back to the system, its location and distribution network characteristics [Baran et al.,2007;Dai et al.,2004;Duan et al.,2009;Masters,2002;Nuroglu et al.,2008].

With the existence of DG units in distribution networks, the following methods can be used for maintaining the proper voltage profiles [Herman et al.,2009]:

- Reinforcement of the network,
- DG reactive power control,
- DG active power control,
- Installation of voltage regulators,
- Use of compensators.

Based on the previous methods, different control strategies have been reported in the literatures. For example, in [Viawan et al.,2008] a coordination between the On-Load Tap Changer (OLTC), switched capacitors at substation, switched capacitor at feeder, and synchronous machine based DG is used for voltage and reactive power control in a distribution network. In [Casavola et al.,2011] the voltage regulation of distribution systems is addressed with the presence of DG. The OLTC voltage set-point is modified based on a command governor approach to determine the OLTC voltage reference that allows the fulfillment of prescribed operating constraints despite the occurrence of adverse conditions.

2.5.2 Power/Energy losses

It is obvious that the network losses depend on the power flow of the system. As DG is integrated, it has an impact on the power flow of the distribution network; the losses of such network will be in turn affected as well [Salman,1996]. Different studies are presented in the literatures for providing how the influence of DG interconnection on the system losses is. In [Quezada et al.,2006] the impact of different DG technologies, penetration, and concentration levels on the energy losses of distribution networks based on different load flow methodologies was investigated. Ayres et al presented in [2009] a sensitivity based methodology for evaluation the influence of DG integration on the power loss. The evaluation process is conducted for different penetration levels, different numbers of DG units, and different operating modes of DG. Gowd et al in [2008] investigated the impact of DG units on the power loss using three phase models for all the components in the distribution network including the DG unit.

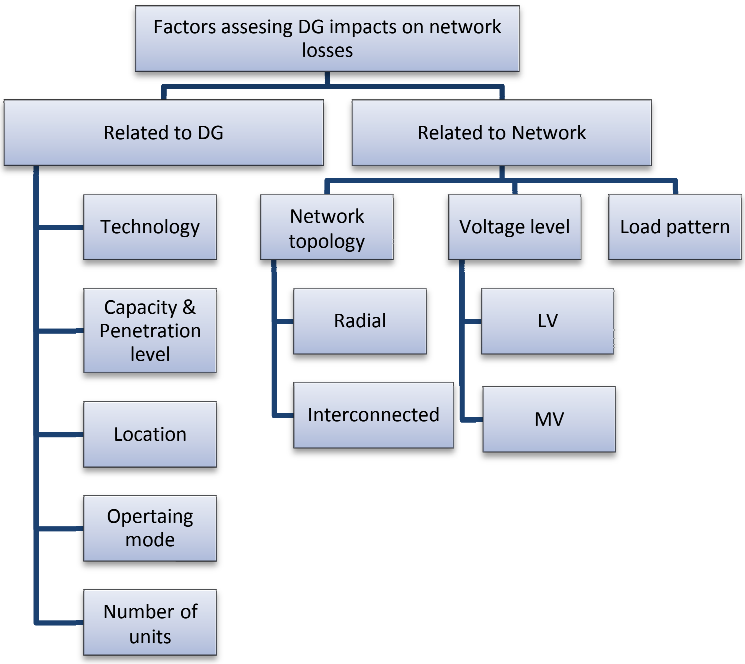

Figure 2 - 6: Different factors assessing the DG impact on power/energy losses

Based on the previous studies in this area [Ayres et al.,2009;Beddoes et al.,2007;Chen,2008;Chiradeja,2005;González-Longatt,2007;Keane et al., 2006;Loevenbruck et al.,2009;Nazari et al.,2006;Thong et al.,2004a] it can be concluded that the impact of DG on power/energy loss can be positive or negative. Moreover, this influence depends on different factors. These factors can be broken into two groups. The first group is related to the DG unit itself and the second group is related to the distribution network where the DG is intended to be interconnected, Fig. 2-6 illustrate theses two groups.

Figure 2-7 shows the variation of the losses of one of the tested systems which are used in this thesis with the variation of the penetration level while the DG is integrated at two different locations. It can be seen that as the penetration level increases the losses start to decrease to reach a certain minimum value, then return back to increase. This means that the DG may has positive impact on the losses by reducing it or in the other side it may has a negative impact by increasing the losses depending on the penetration level.

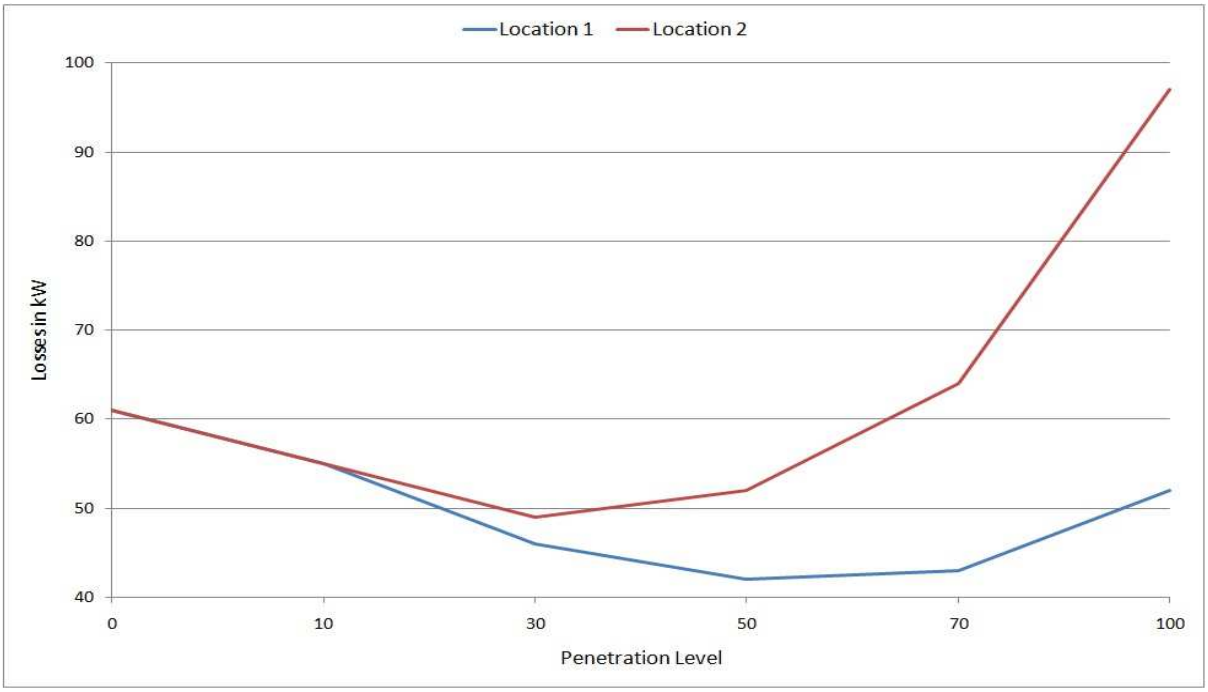

Figure 2 - 7: Variation in the losses with penetration level

2.5.3 Reliability

A widely accepted definition for reliability involved two elements: adequacy, the ability to satisfy market demand at all times, and security, the ability to withstand sudden disturbances such as short circuits or unanticipated loss of system elements [D.Little,2000]. If the DG unit is used as a standby power supply, therefore it can enhance the power supply system reliability. However, if there is a parallel operation between DG and power network, the reliability of power supply system is possible to be weakened[Wang,2009].

There are several ways where DG can improve the reliability of the distribution networks such as [D.Little,2000;Honton,2000]:

- Energy company purchase during peak periods,
- Aggregating backup assets for sale to grid,
- Utility provision of premium power,
- Allocate DG to circumvent T&D constraints.

- Adding generation capacity at the customer site for continuous power and backup supply
- Adding system generation capacity
- Freeing up additional system generation, transmission and distribution capacity
- Relieve transmission and distribution bottlenecks
- Supporting power system maintenance or restoration operations with generation of temporary backup power

2.5.4 Power quality

Power quality is identified in a quite different way, depending on one's frame of reference. The utility may define power quality as reliability of its system. A manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly [Dugan,2003]. As the DG is introduced the distribution networks an interaction between the power quality problem caused by the DG itself and power quality problems come from the distribution network and affect the DG unit [Latheef et al.,2008].

The main power quality issues affected by DG are [Dugan,2003]:

- *Sustained interruptions:* Many generators are designed to provide backup power to the load in case of power interruption. However, DG has the potential to increase the number of interruptions in some cases,
- *Voltage regulation:* This is the most limiting factor for how much DG can be accommodated on a distribution feeder without making changes,
- *Harmonics:* There are harmonics concern with both rotating machines and inverters, although concern with inverters is less with modern technologies,
- *Voltage sags:* This is a special case because DG may or may not affect, and
- *Voltage flickers:* Voltage flicker is the rapid and repetitive change of voltage that causes visible fluctuations in the light output. Generally, flicker can be caused by load fluctuations as well as source fluctuations. DG units have the potential to cause unwanted fluctuations and cause noticeable voltage flicker in the local power grid. Step changes in the outputs of the DG units with frequent fluctuations and the interaction between DG and the voltage controlling devices in the feeder can result in noticeable lighting flicker [Azmy,2005].

2.5.5 Distribution system protection

The distribution networks are traditionally designed to be operated in radial where the power flows in unidirectional. As the DG units are integrated into the network, it will be converted from simple systems into complex networks, which needs essential modifications in protection systems. Different typical feeder protection problems, which can be raised by integration of high penetration level of DG, can be stated as follows [Azmy,2005]:

- Change of the short circuit current level
- Fast tripping of feeders
- Preventing the operation of feeder protection
- Unwanted islanding

2.6 DG and System Loadability

In practical way, loadability of distribution networks is limited by voltage drop as most of the distribution feeders are long and operating at low voltage level [Lomi et al.,2009;Mithulananthan et al.,2006]. Different studies in the literatures are focused on the influence of DG unit's interconnections on the loadability of distribution networks.

The loadability aspect which is presented in the literatures is the Voltage Stability Limit Loadability (VSLL). Voltage stability concerns stable load operation, and acceptable voltage levels all over the system nodes. Its instability has been classified into steady state and transient voltage instability, according to the time spectrum of the occurrence of the phenomena. A power system is said to have entered a state of voltage instability when a disturbance causes a progressive and uncontrollable decline in voltage [El-Sadek,2002;Huang et al.,2001]. Voltage stability analysis often requires examination of lots of system states and many contingency scenarios. For this reason the approach based on the steady state analysis is more feasible, and it can also provide global insight of the voltage reactive power problems [Huang et al.,2001]. The voltage stability phenomenon has been well recognized in distribution systems. Radial distribution systems having a high resistance to reactance ratio causes a high power loss, so that the radial distribution system is one of the power systems, which may suffer from voltage instability [El-Sadek,2002;Moghavvemi et al.,2002].

Thong et.al [2004c;2003a;2003b;2005;2007] investigated the effect of synchronous and induction based DG units on the static voltage stability of distribution networks by evaluating the P-V nose curves at a selected node. It has been found that the integration of DG will generally improve the voltage stability of the distribution system. Moreover, it has been drawn from this work, that DG supports the voltage at nearby nodes and has less impact on distant nodes. Moreover, it has been found that synchronous generator based DG has the ability to improve the voltage stability compared to the induction generator which has negative impact. Jaganathan et.al [2004] analysed the steady state voltage stability of three different systems with the integration of DG using P-V and Q-V curves at certain buses. The authors concluded that DG has the ability to improve the voltage collapse margin. Therefore, the power system with the existence of DG will be less vulnerable to a collapse when subjected to a disturbance. This work also showed that the DG location and system loads affecting the enhancement level on the voltage stability. This study dealt with DGs which have the ability to provide reactive power.

Jenkins et al [1997] investigated the voltage stability of distribution systems with the integration of fixed speed wind turbines using P-V method. It has been shown in this study that relatively high ratios of wind farm capacity to network short circuit level can be accommodated successfully if the conditions are favourable. However, the voltage stability of the system is likely to be an important limiting factor to the continued increase of the ratio of generation capacity to network short circuit level. Mariotto, et al [2007a;2007b] evaluated the steady state voltage stability of distribution systems with the existence of wind power generation. The impact of wind generation on voltage stability was analysed by plotting P-Q plane of stability for different operation scenarios of wind power generation. This study has been demonstrated that the wind power capability limits can impose operational restrictions to the power system voltage stability limits.

Ramesh et al [2008] evaluated the voltage stability of distribution systems by observing the voltage profile of the system with the integration of DG. It has been found that the voltage profile which has taken as an indicator for voltage stability is enhanced with the existence of DG. Chen et al [2006] used a static voltage stability index (L) [Jasmon et al.,1993] to analyse the voltage stability of distribution systems with DG at different load increasing scenarios. It has been observed that the asynchronous generator based DG has a negative impact on the system steady state voltage stability, and that is because it absorbs reactive power at the PCC as it is integrated to the network. However, the synchronous generator based DG has the potential to improve the voltage stability of the distribution network.

As a conclusion of the literature review, it can be inferred that according to our knowledge approximately all the researchers dealing with the loadability of the distribution networks with the existence of the DG as the VSLL. In the presented work the loadability of the distribution networks will be evaluated according to two different loadability aspects, namely voltage limit loadability (VLL), and VSLL. The VLL can be defined as the maximum loading which can be supplied by the power system while the voltages at all nodes are kept within the limits. The evaluation of the two loadability aspects is performed using the CPF. Different DG capacities, locations, and operating modes are taking into consideration through the simulation. Moreover, the voltage stability of distribution networks is investigated with connecting of different DGs capacities and locations using a previously introduced voltage stability index [Chakravorty et al.,2001] which can be evaluated at each node of the system.

2.7 Placement and Sizing of DG Units

The planning of distribution networks in the presence of DG requires the definition of different parameters, such as the best technology to be implemented, the number and capacity of the DG units, the best location, the type of network connection, etc. The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and therefore, having an effect opposite to the desired. However, the selection of the best places for installation and the size of the DG units in large distribution systems is a complex combinatorial optimization problem [Borges et al.,2006]. In the developing countries, where the utilities already facing the problem of high power losses and poor voltage profiles because of high loads, theses utilities need the DG to be integrated properly, so it takes the advantages of improving the loadability, reducing the losses and improve the reliability of the supply [Acharya et al.,2006;Borges et al.,2006]. Different technical issues have been considered in different studies of optimal integration of DG to achieve different benefits. Figure 2-8 shows the different objectives of DG placement and sizing.

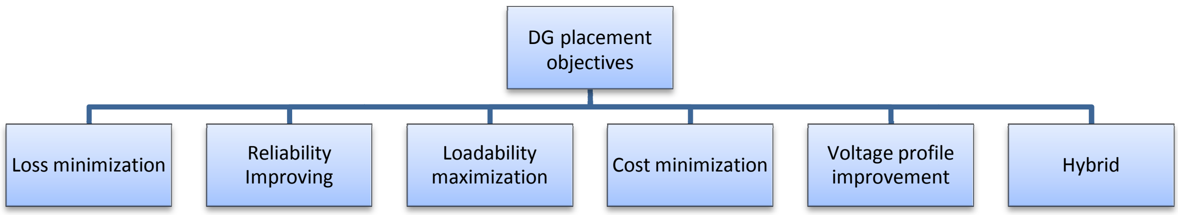

Figure 2 - 8: Different objectives of DG placement and sizing

Loss minimization is the most objective which has been reported in the literatures. Different methodologies (see Fig. 2-9) have been implemented for minimizing the losses of the distribution network through the placement and sizing of DG units. Such as analytical methods, Genetic Algorithm (GA) , Ant Colony, Evolutionary Programming (EP) , Fuzzy System (FS) , and Tabu-Search (TS) [Acharya et al.,2006;Gözel et al.,2009;Griffin et al.,2002;Wang et al.,2004].

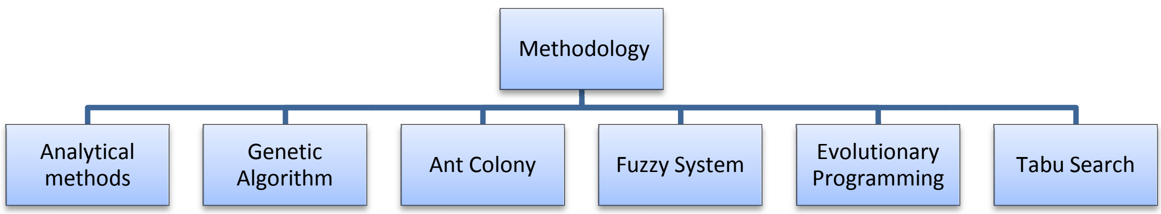

Figure 2 - 9: Different methodologies used for DG placement

However, a little work has been conducted for improving the loadability, and the loadability which is considered as an objective in the literatures is the voltage stability limit. Mithulananthan et al in [2006] has introduced a methodology where the tangent vector and right eigenvector method are implemented to define the weakest bus in the network. Then the DG is integrated at that bus. It was found that interconnecting of DG at this bus improving the voltage stability margin of the system, reducing the main feeder current, reducing the losses, and enhancing the voltage regulation. Lomi et al in [2009] has introduced a methodology based on identifying the weakest bus on the network through the evaluation of the voltage stability index. Then the DG is recommended to be integrated at that bus in order to enhance the VSLL. It has been found that for the DG which supplies active power only, the weakest bus might not be the best choice for improving the voltage stability. Moreover, it has been found that the DG which is capable of supplying active and reactive powers gives more improvement in the VSLL than injecting reactive power only at that node.

Hedayati et al in [2008;2006] have introduced a method for improving the voltage stability margin based on continuation power flow. This method is a multi objective method, i.e. voltage profile improvement, power losses reduction, power transfer capacity enhancement and, VSLL improvement. The methodology is based on placing multi DG unit's at the most sensitive voltage buses to collapse. Then two or more DG units with the same capacities are placed at these buses. Alonso et al in [2009] employed the GA to find the optimal point of connection of different DG units, with VAR capability, in order to maximize the VSLL of the system.

Analyzing these scientific literatures, it can be concluded that a small number of studies have considered the maximization of the system loadability of the distribution network through the optimal placement of the DG units. Moreover, the loadability which is considered in this small number of studies is the VSLL. While the installation of DGs in certain locations to meet the increasing demand can reduce or avoid the need for building new T&D lines and upgrade the existing power systems [El-Khattam et al.,2004]. It is needed to present a methodology for identifying different recommended nodes for interconnection of different number of DG units for enhancing the voltage limit loadability (VLL). Moreover, maximize the benefits in that issue from the same amount of DG power. In the current study an efficient method for identifying different nodes for integrating the DG to improve the VLL is presented. This method is based on dispersing the DG supplied power between different recommended nodes for maximizing the benefits which can be obtained from a certain amount of power. The suggested methodology is developed based on CPF.

2.8 Decentralized Wind Power Generation Impacts on MV Networks

As the cost of wind energy is declined, the interest in a small wind energy installation within the distribution networks is growing while the cost of interconnecting to the high voltage transmission system is usually cost prohibitive for one or a few large wind turbines [AWEA,2005;Wind et al.,2005].

The study which was presented in [Forsyth et al.,2007] clarified seven market segments for Decentralized Wind Power Generation (DWPG). These market segments were defined in that study as follows:

- Small-scale remote or off-grid power: supplying energy to rural, off-grid applications in the developed and developing world.
- Residential or on-grid power: small wind turbines used in residential settings that are installed on the house side of the home electrical meter using net metering to supply energy directly to the home. Excess energy is sold back to the supplying utility.
- Farm, business, and small industrial wind applications: supplying farms, businesses, and small industrial applications with low-cost electric power.
- “Small-scale” community wind: using wind turbines to power large, grid-connected loads such as schools, public lighting, government buildings, and municipal services. Turbines can vary in size from very small, several-kW turbines to small clusters of utility-scale multi-megawatt turbines.
- Wind/diesel power systems: providing power to rural communities currently supplied through diesel technology in an effort to reduce the amount of diesel fuel consumed. The rising cost of diesel fuel and increased environmental concerns regarding diesel fuel, transportation, and storage have made project economics more sensible.
- Irrigation water pumping: using wind turbines to supply energy for agricultural applications. Current applications are powered by grid electricity, diesel, gasoline, propane, and particularly natural gas. Wind or hybrid systems allow farmers to offset use of high-priced fossil fuels.
- Water desalination: using wind energy to directly or indirectly desalinate sea or brackish water using reverse osmosis, electro dialysis, or other desalination technologies. The economic and technical performance of wind-powered desalination depend on the configuration and placement of wind resource with regard to the impaired water and existing energy resources. Water desalination works better with the wind resource found in coastal or desert environments.

DWPG can provide different benefits for the generation system, transmission system, and distribution system. These benefits depend on the following [Cohen et al.,2001]:

- Wind generator type, reliability, and wind turbine power output curve,
- Number of turbines and their location on local utility distribution networks,
- wind resource characteristics
- Characteristics of the subtransmission and distribution systems near the proposed wind site,
- The ability of the local distribution system to meet customer load and service requirements, including voltage, tolerance for outages, and peak power demand,
- Transmission system characteristics, in particular reliability criteria and loading levels,
- Generation system characteristics, including generator types, installed capacity, native load shape, and growth,
- Ownership of turbines, generation, transmission, and distribution systems (i.e., vertically integrated utility, distribution utility, utility customer, regulated versus unregulated power company), and
- Size of demand charges.

Because of wind's intermittent nature, wind generation projects will usually require individual analysis to determine the presence and extent of distribution system benefits [Cohen et al.,2001].

Technical issues related to the interconnection of DWPG into the distribution networks are of great importance [AWEA,2005]. Voltage flicker, harmonics, reactive power compensation, voltage rise, network energy losses, voltage ranges, energy storage, and network stability are some of these important technical issues which can affect or judge a new DWPG integration.

Different studies have demonstrated that decentralized and properly sized wind mills will not only have a positive effect on reducing the losses, but could also improve the voltage quality. In addition, showed how DWPG could change the network expansions due to the expected increase in the electrical energy demand. However, since wind is a highly intermittent energy source, it is claimed that any benefit is likely to be small and will be site-specific [Korpås,2004].

A study in [Wind et al.,2005] was performed to determine the ability for interconnecting large wind turbines to a typical distribution system in northeastern Colorado, USA. The impacts of DWPG on the voltage flicker, harmonics, and voltage rise are evaluated. It has been found that voltage flicker in that case study was the limiting factor to connect large wind turbines but the substation transformer capacity can be in some cases different limiting factors. Like other DG types, DWPG (especially when it based on synchronous generator) influenced the protection of the distribution network. This impact can be, increasing on the fault current levels, prevention of feeder protection, unnecessary disconnection of healthy feeders, and feeder coordination problems [Maki,2004]. However, it was found that with appropriate adjustments of the system protection settings, the system operation can be improved [Papazoglou et al.,2003].

Agalgaonkar et al in [2003] investigated the impact of DWPG on the system losses and the voltage profile. The study was conducted on a real network in India. The load profile is divided into four zones while the wind profiles are averaged and the average values are implemented on the analysis. It has been found that the maximum reduction in the losses was occurred when the system load requirement and wind generation match. Also, an improvement on the voltage profiles has been observed.

Improvement of the voltage profile with the existence of DWPG was discussed in [Chiradeja et al.,2003]. The simulation has been conducted on a simple case study. A method based on probabilistic approach involving the application of convolution is developed to quantify the output of DWPG. The results of this study showed that DWPG can improve voltage profile at load point. The expected value of the load voltage goes up as the DWPG is moved closer and closer to the load point and as the Wind Turbine Generator (WTG) rating increases. Moreover, different issues related to DWPG are addressed in the literatures, such as the impact of DWPG on the reliability of distribution networks in [Zeng et al.,2010] and introduction of optimization methods for maximizing the interconnection of DWPG into distribution networks based on time series models of the loads and the wind power [Ochoa et al.,2007;Ochoa et al.,2008].

In the current work an evaluation of the implications of DWPG on a real MV distribution network is introduced. The evaluation is based on time-series of load and wind power. The load profiles of households which are connected at the low voltage side of the transformer at each MV station are modeled using the VDEW standard load profiles. Measured data of three wind mills which are already integrated into the network is used in the simulation. Based on some measured data, a new relation for calculating the maximum power which can be consumed simultaneously for a group of households is presented. The impact of DWPG on the voltage ranges, voltage profiles, energy losses, line loading, and the power supplied from the main station are presented. Finally, the availability to interconnect a new wind mill to the network is tested according to the specifications presented by the German Association of the Energy and Water Industries (BDEW).

2.9 Reconfiguration of MV Distribution Networks

Recently, there has been a growing interest in Distribution Automation (DA) leading to Smart Grid. One of the DA functions is the network reconfiguration. Reconfiguration is the process of altering the configuration of the distribution network by changing the status of the switches without violating operating constraints. Reconfiguration is mainly done for loss reduction, relief of overloads (load balancing), volt/var support (maximizing loadability), and restoration [Khushalani,2006]. The loss reduction in distribution system can be efficient to reduce transmission loss in the whole power system. There are many alternatives available for reducing losses at the distribution level: reconfiguration, capacitor installation, load balancing, introduction of higher voltage levels, and reconductoring. Despite the numerous methods existing for reducing the losses, local utilities may be reluctant to adopt measures which represent considerable financial expenditure [Sarfi et al.,1994].

The reconfiguration algorithms can be classified by the solution methods that they employ as follows [Sarfi et al.,1994]:

- Algorithms based upon a blend of heuristics and optimization methods
- Algorithms based solely on heuristics,
- Artificial Intelligence (AI) based techniques.

A large number of studies have been reported so far on reconfiguration of distribution networks. These works can be mainly classified from the point of view of the present work into two parts, reconfiguration of distribution network with and without of DG.

2.9.1 Reconfiguration of distribution networks without DG

Reconfiguration of distribution networks without DG has been performed in different studies taking into account two aspects, using the maximum or average load values at all nodes of the system and using load profiles.

- ***Using maximum load***

In terms of the first aspect, different reconfiguration techniques have been reported such as using of heuristic methodologies [Gomes et al.,2005;Jaswanti et al.,2007;Raju et al.,2008;Yehia et al.,2002], using network partitioning [Sarfi et al.,1996]. Moreover, different AI techniques have been implemented to solve the reconfiguration optimization problem.

GA is implemented where it has an interesting feature which searches from a population of points and not from a particular search point, so that there is a possibility of obtaining an optimal solution very rapidly [Sarfi et al.,1994]. GA has been used solely as in [Fudou et al.,1997;Subburaj et al.,2006] to find the optimum configuration for reducing the losses.

FS is also implemented for distribution networks reconfiguration with loss minimization as a single objective [Sahoo et al.,2007] or for providing multiobjectives such as minimization of real power loss, minimization of the deviations of nodes voltage, minimization of the branch current constraint violation, and feeder load balancing subject as presented in [Das,2006].

TS is also functioned for optimal reconfiguration of distribution networks in order to minimize the power loss. TS is a metaheuristic superimposed on another heuristic. The basic approach aims to avoid being trapped in cycles by preventing or penalizing moves which take the solution, in the next iteration, to points in the solution space which were previously visited [Guimaraes et al.,2005]. Different works using TS have been reported in [Abdelaziz et al.,2010;Guimaraes et al.,2005;Hayashi et al.,2006;Mekhamer et al.,2008;Xiong et al.,2008;Xu et al.,2009;Zhang et al.,2007].

- ***Using load profiles***

Regarding the second aspect where the load profiles are taking into account in the reconfiguration process of distribution network, different studies were reported in the literatures. Wagner et al [1991] introduced a comparison of various methods applied to feeder reconfiguration for loss minimization. Moreover, a linear programming technique and a new heuristic search method were presented for the comparison. These different methods have been implemented on a large system based on a model of real network. Load profiles for residential, commercial, and industrial have been used through one year. The results showed that heuristic approaches, although can provide substantial savings if properly formulated and are suitable for real-time implementation.

Lopez et al [2004] presented the dynamic programming for minimizing the loss in real distribution networks by reconfiguration. The study was performed including the demand aspects such as the model itself (constant power, constant Impedance, or constant current), the actual type of load (industrial, commercial, residential, and mixed), and hourly variation. This study showed that a loss reduction can be obtained when the network is reconfigured hourly. However, this reduction may be not relevant when compared with losses obtained with a fixed topology optimized for maximum or average demand. It has been concluded that it is not sure that a general response can be given. Therefore a specific study should certainly be carried out for any given network. Moreover three different studies using time varying loads were presented [Broadwater et al.,1993;Chen et al.,1993;Shin,1994].

2.9.2 Reconfiguration of distribution networks with DG

The introduction of DG in power distribution networks will increase the complexity of the reconfiguration problem. Reconfiguration of distribution networks can be conducted considering the load profile, generation profile, hybrid (i.e. load and generation profiles), constant load, or constant generation. A small number of studies have been reported which deals with reconfiguration problem with the existence of DG units. A short overview on these studies will be discussed briefly in this section.

Agustoni et al in [2002] investigated the influence of DG on the distribution networks using a time variant load and a constant output power of DG. The results have been shown that reconfiguration can be used to alleviate the voltage rise produced by introducing the DG units. The analysis was performed on a simple system. Oliveria et al [2004] presented a distribution networks graphic simulator, developed with reconfiguration functions and a special focus on loss allocation, both considering the presence of DG. The reconfiguration problem was solved through a heuristic methodology. That method was implemented for constant power factors DG at certain location and at a certain values of the loads. The results showed that different configurations can be obtained for the network with DG compared to the network without DG.

Choi et al in [2000a] used the GA for reconfiguration of a distribution network with the existence of DG units. The DG unit was considered supplying a constant power at a certain power factor. The results of this study showed that the topological structures of optimum network without DGs are different from those with DG. Calderaro et al [2006] implemented the reconfiguration of distribution networks for maximizing the capacity of DG which can be interconnected while the operating constraints are kept within their limits. The reconfiguration process was performed based on GA. Constant load and DG was taken into consideration. The results showed that optimal reconfiguration of distribution networks can help the distribution systems operator to increase the penetration level of DG units. Rugthaicharoencheep et al [2009a;2009b] implemented the TS for optimal reconfiguration of distribution systems with the existence of DG units to minimize the power loss. The given methodology was applied on a distribution network and the results showed that although the DGs can contribute to loss reduction, some bus voltages violate the minimum voltage constraint. Such a problem can be remedied by feeder reconfiguration. Not only these bus voltages improved, but also the system power loss can be further reduced.

Mishima et al [2005] has implemented the TS for reconfiguration of distribution networks. The authors have developed their method dealing with the loads are distributed equally in the section. Different assumption has been taken into consideration while dealing with the distribution system, such as the load is taken as a constant current, the load power factor is unity, the lines have only resistance and reactance, the installation points of the DG units are known, all tie and sectionalizing switches are switchable, and the DG are handled as constant current source. The algorithm was implemented in different cases, such as the system without DG, only on DG is existing, and multiple DG's are connected. As the methodology is implemented for one operating point the objective function was to reduce the power loss. The results show that the algorithm can minimize the power loss by 14, 36, and 19% for the former three cases, respectively. However, voltage and current constraint violations have been found regarding the second case.

From the above review the following points can be drawn:

- A little number of studies has been performed in the area of reconfiguration of distribution networks with DG units.
- The reported works dealt with the power of DG as a constant value and that is not valid especially for DG based on renewable energies.
- The reported works take all the tie and sectionalizing switches in the distribution network available to be altered, while the case in reality may be different.

In the present work, optimal reconfiguration of typical networks with the existence of DG units will be presented. Different DG technologies are implemented with their generation profiles. Switches at the two ends of each branch have been considered for reconfiguration process to match the reality. The optimization is conducted based on TS and branch exchange combination. The reconfiguration algorithm was built based on NEPLAN – power system analysis software- and C++ programming language.

CHAPTER 3: IMPACTS OF DG ON VOLTAGE STABILITY AND VOLTAGE LIMIT LOADABILITY OF MV DISTRIBUTION NETWORKS

The introduction of DG in the distribution networks changes the operating features and has significant technical and economic impacts [Khan et al.,2010]. This chapter introduces the study of the impact of DG interconnection on the voltage stability and loadability of MV distribution networks. The chapter can be divided into two parts. In the first part the effect of DG capacity and location on voltage stability enhancement of radial distribution systems is investigated. The analysis process is performed using a steady state voltage stability index presented by Charkravorty et al in [2001]. This index can be evaluated at each node of the radial distribution system. The optimal capacities and locations of DG for a 69 node distribution network evaluated by Harrison and et al in [2007] are implemented in the simulation.

In the second part of this chapter the impacts of DG integration on different loadability aspects of MV distribution systems will be introduced. As concluded in the previous chapter the loadability of distribution systems is always evaluated according to the VSLL. In this part the loadability of the distribution systems is evaluated according to two aspects, the VLL, and VSLL. The importance of the first aspect (VLL) comes from a practical point of view. The loadability is examined with the integration of DG at each node of the system. CPF method is implemented for assessing the networks loadability with respect to the two aspects using Power System Analysis Toolbox (PSAT) [Milano,2005] which has been integrated into MATLAB. The impact of reactive power supplied from DG on active and reactive power losses is also evaluated. Normally, the real power loss draws more attention for the utilities as it reduces the efficiency of the transmitting energy to customers. Nevertheless, reactive power loss is obviously not less important. This is due to the fact that the reactive power flow in the system needs to be maintained at a certain amount for sufficient voltage level. Consequently reactive power makes it possible to transfer real power through transmission and distribution lines to customers [Ramesh et al.,2008].

3.1 Voltage Stability Evaluation Using a Voltage Stability Index

An index, which can be evaluated at all nodes in radial distribution systems, was presented in [Chakravorty et al.,2001]. The equations used to formulate this index are presented in [Das et al.,1995] to solve the load flow for radial distribution systems.

For the two bus system shown in Fig. 3-1 the following equations can be written:

$$I = \frac{|V_{m_1}|\angle\delta_{m_1} - |V_{m_2}|\angle\delta_{m_2}}{R_{jj} + jX_{jj}} \tag{3.1}$$

$$P_{m_2} - jQ_{m_2} = V_2^* I \tag{3.2}$$

Equations (3.1) and (3.2) can be rewritten as follows:

$$\frac{|V_{m_1}|\angle\delta_{m_1} - |V_{m_2}|\angle\delta_{m_2}}{R_{jj} + jX_{jj}} = \frac{P_{m_2} - jQ_{m_2}}{V_2^*} \tag{3.3}$$

Therefore

$$[V_{m_1}\angle\delta_{m_1} - V_{m_2}\angle\delta_{m_2}]V_{m_2}\angle{-\delta_{m_2}} = [P_{m_2} - jQ_{m_2}][R_{jj} + jX_{jj}] \tag{3.4}$$

Separating real part and imaginary part of Eq. (3.4), gives:

$$V_{m_1}V_{m_2}Cos(\delta_{m_1} - \delta_{m_2}) = P_{m_2}R_{jj} + Q_{m_2}X_{jj} + V_{m_2}^2 \tag{3.5}$$

$$V_{m_1}V_{m_2}\,Sin(\delta_{m_1} - \delta_{m_2}) = P_{m_2}X_{jj} - Q_{m_2}R_{\mathrm{jj}} \tag{3.6}$$

Squaring and adding Eqs. (3.5) and (3.6) the following equation can be obtained:

$$V_{m_1}^2V_{m_2}^2 = \left[(P_{m_2}R_{jj} + Q_{m_2}X) + V_{m_2}^2\right]^2 + \left[P_{m_2}X_{jj} - Q_{m_2}R_{jj}\right]^2 \tag{3.7}$$

After some mathematical manipulation the following equation can be obtained:

$$V_{m_2}^4 + \left[2(P_{m_2}R_{jj} + Q_{m_2}X_{jj}) - V_{m_1}^2\right]V_{m_2}^2 + \left[(P_{m_2}^2 + Q_{m_2}^2)(R_{jj}^2 + X_{jj}^2)\right] = 0 \tag{3.8}$$

Note that Eq. (3.8) has four possible solutions. However, under normal load conditions (within the voltage stability limit), the equation has only two feasible (real and positive) solutions [Haque,1995]. Take,

$$V_{m_2}^2 = H \tag{3.9}$$

Equation (3.8) will be a quadratic equation:

$$aH^2 + bH + c = 0 \tag{3.10}$$

For Eq. (3.10) the constants a, b, and c will be:

$$a = 1 \tag{3.11}$$

$$b = \left[2(P_{m_2}R_{jj} + Q_{m_2}X_{jj}) - V_{m_1}^2\right] \tag{3.12}$$

$$c = \left(P_{m_2}^2 + Q_{m_2}^2\right)\left(R_{jj}^2 + X_{jj}^2\right) \tag{3.13}$$

The solution for $V_{m_2}^2$ from Eq. (3.10) will be:

$$V_{m_2} = \sqrt{\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}} \tag{3.14}$$

For realistic data, when P_{m_2}, Q_{m_2}, R_{jj}, X_{jj}, and V_{m_2} are expressed in per unit (b) is always negative [Chakravorty et al.,2001], because the term $\left[2\left(P_{m_2}R_{jj} + Q_{m_2}X_{jj}\right)\right]$ is small as compared to $V_{m_1}^2$and $(4ac)$ is negligible compared to (b^2). Note that the system reaches the critical point when the discriminator becomes zero. Applying the above condition for Eq. (3.14) and from Eqs. (3.11), (3.12), and (3.13) the following equation will be obtained:

$$[2\left(P_{m_2}R + Q_{m_2}X\right) - V_{m_1}^2]^2 - \left[4\left(P_{m_2}^2 + Q_{m_2}^2\right)\left(R_{jj}^2 + X_{jj}^2\right)\right] = 0 \tag{3.15}$$

Equation (3.15) can be used to define a voltage stability index (SI) at node m_2 and it will be:

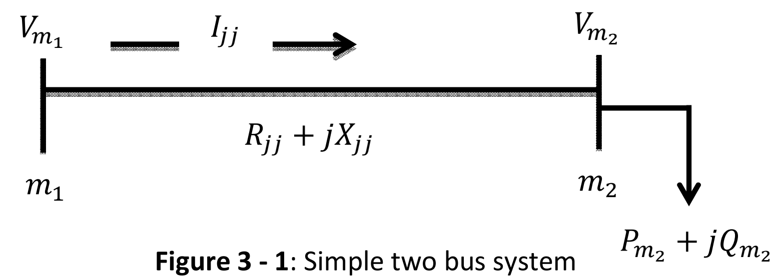

Figure 3 - 1: Simple two bus system

$$SI_{m2} = |V_{m1}|^4 - 4 \times \left\{\left(P_{m2}X_{jj}\right) - \left(Q_{m2}R_{jj}\right)\right\}^2 - 4 \times \left\{\left(P_{m2}R_{jj}\right) - \left(Q_{m2}X_{jj}\right)\right\}|V_{m1}|^2 \tag{3.16}$$

Where

jj is the branch number,

R_{jj} is the resistance of branch jj,

$X_{jj}$is the reactance of branch jj,

$V_{m_1}$is the voltage at node m_1,

V_{m_2} is the voltage at node m_2,

P_{m_2} is the total real power fed through node m_2, and

Q_{m_2} is the total reactive power load fed through node m_2.

Actually this index is derived for the two nodes equivalent system shown in Fig. 3-1, but it can be generalized by the same method used in [Das et al.,1995] where P_{m_2} and Q_{m_2} will be as follows:

P_{m_2} = Sum of the real power loads of all the nodes beyond node m_2 plus the real power load of node m_2 itself plus the sum of the real power losses of all the branches beyond node m_2

Q_{m_2} = Sum of the reactive power loads of all the nodes beyond node m_2 plus the reactive power load of node m_2 itself plus the reactive power losses of all the branches beyond node m_2

The value of SI is zero when the voltage at the node under study approaches the critical collapse point. For stable operation the value of SI must be ≥ 0. As the value of this index is increased, this means that the voltage at that node is more stable i.e. the voltage stability margin is increased.

3.1.1 Case study

The 69-node distribution network [Das,2006] used in this part is depicted in Fig. 3-2. It is a 11-kV radial distribution system having two substations and four feeders. Data for this system are given in the Appendix A.

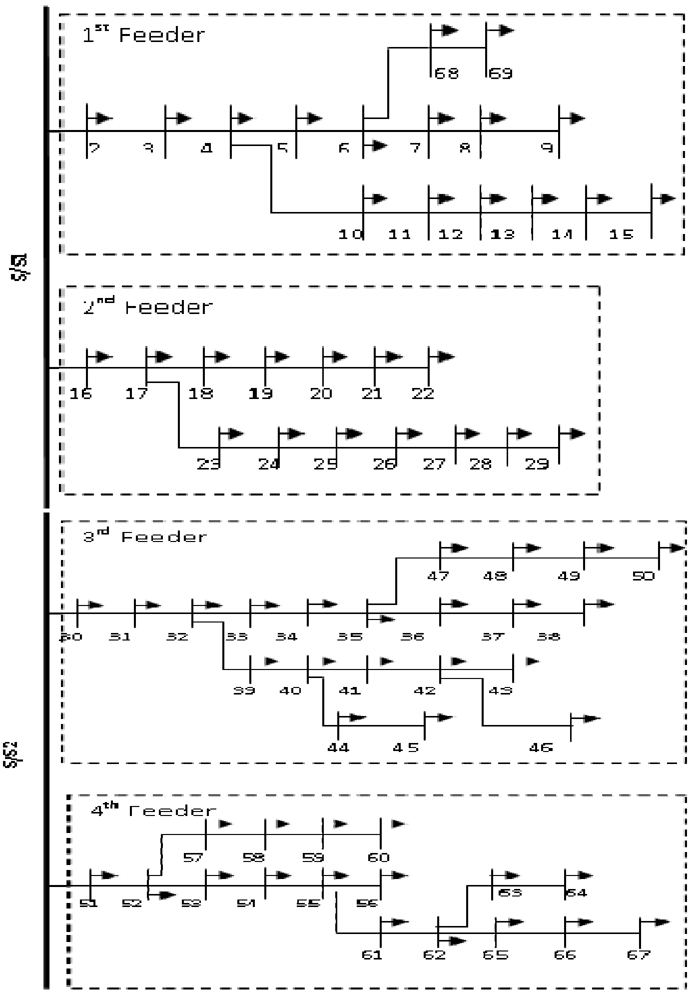

Figure 3 - 2: 69 Node radial distribution network

Harrison et al [2007] presented a method combining Optimal Power Flow (OPF) and GA to find the best combination of sites within a distribution network for connecting a predefined number of DG. The results of optimal capacity and location of DG for the 69 node distribution system are illustrated in Table 3-1. The results are evaluated for four integration cases of 3, 5, 7 and 9 DG units into the distribution system. These results are obtained assuming that all the generators operate at a power factor of 0.9.

Table 3 - 1: Optimal locations and sizes of DG units for different cases [Harrison et al.,2007]

		DG capacity added (MW)			
Feeder	**Node**	**3 DG 1st Case**	**5 DG 2nd Case**	**7 DG 3rd Case**	**9 DG 4th Case**
1st Feeder	8		1.769		
	9			1.672	1.648
2nd Feeder	17		0.041	0.055	
	18	2.634			
	19		2.885		
	20				2.402
	22			1.801	
	26				0.101
	28				0.103
	29			0.216	0.119
3rd Feeder	38	0.424	1.823	1.867	1.884
	40			0.059	
	42				0.060
4th Feeder	52	4.028			
	55				1.001
	64		0.862	1.725	1.155
Total		**7.087**	**7.379**	**7.394**	**8.472**

3.1.2 Results and discussion

The effect of DG capacity and location on the voltage stability enhancement of the 69 node distribution system is analyzed. In order to study the effect of DG of different capacities and locations of 69 node distribution network, SI index is evaluated. First, a load flow solution for the system using Newton-Raphson load flow method is performed. Then, the results of the load flow are used to evaluate the line losses and the powers P_{m_2} and Q_{m_2} at each node. Finally the SI index has been evaluated. This process was repeated with the existence of 3, 5, 7 and 9 DG units at different locations of the distribution network which represents the four cases respectively. In this study, the voltage at the main station is maintained at 11 kV. As a result, the integration of DG at a specified feeder has no voltage effect on the other feeders. Therefore, the results of each feeder are discussed separately hereafter.

- ***The first feeder***

Fig. 3-3 shows the voltage stability of the 1st feeder for different cases. It can be seen that there is no difference between the base case and the 1stcase (3 DG) for the first feeder. This is because there is no integration of DG in this case. As the DG integrated in the 1st feeder the voltage stability is enhanced and the voltage margins increase. It can be seen that, the voltage stability enhancement of the 3rd and 4th cases are approximately the same and that is because approximately equal DG power is connected at node No. 9 (1.672 and 1.648, respectively). Moreover, it can be noticed that integrating a DG unit at node No. 8 of 2nd case with a power 1.769 MW will enhance the voltage stability more than integrating 1.672 MW at node No. 9. The main difference can be clearly seen at the region contained nodes No. 2, 3, 4, 5, 6, and 7, while for the other regions the same effect can be noticed.

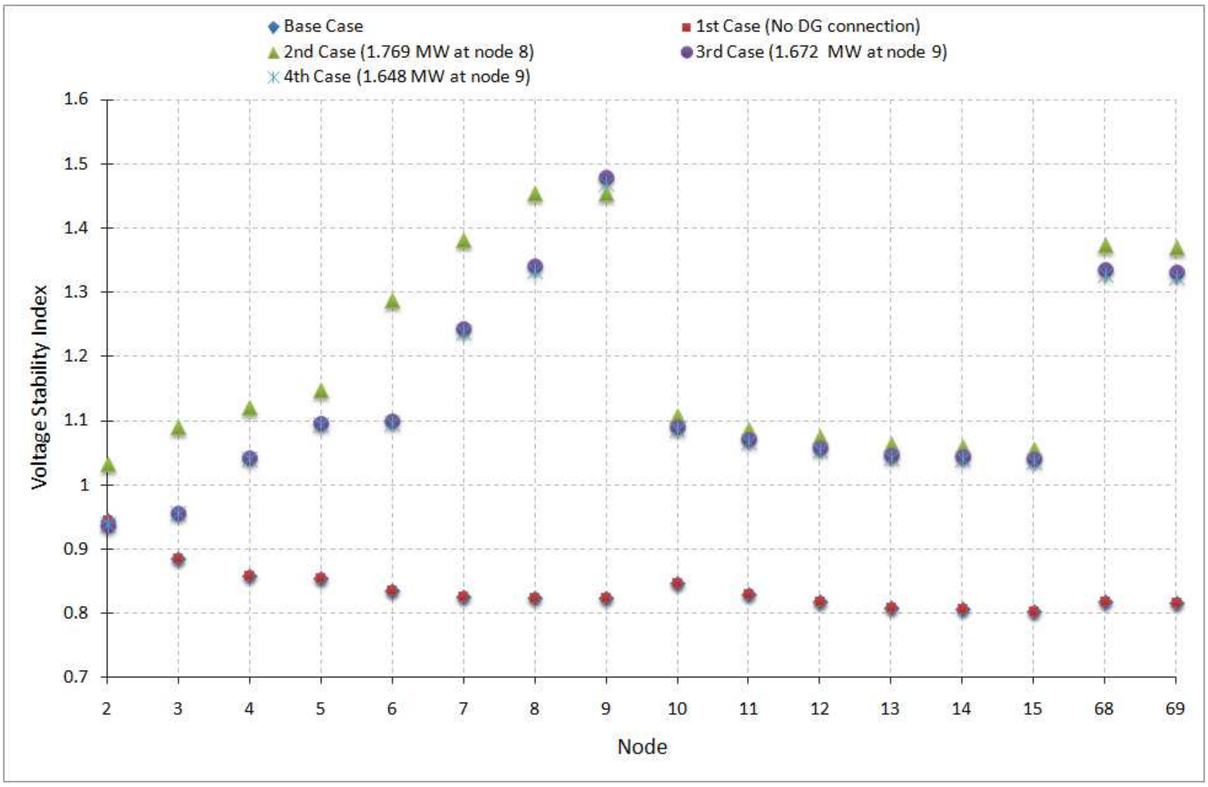

Figure 3 - 3: Voltage stability of the 1st feeder with integration of DG units

- ***The second feeder***

The results of the voltage stability of the 2nd feeder are shown in Fig. 3-4. It can be demonstrated that the total DG power (MW) for the 1st (3 DG) and 4th (9 DG) cases are approximately the same (2.634 and 2.725 MW, respectively). However, it is clear that voltage stability is enhanced in the 4th case more than the 1st case and that is because the

DG power is dispersed in the 4th case through the feeder at four locations (nodes No. 20, 26, 28 and 29). Moreover, when the 1st case is compared with the 3rd case (7 DG), it can be found that the voltage stability is approximately enhanced by the same level while there is a difference in the DG power of 562 kW lower in the 3rd case, this is also due to dispersing of the DG power through the feeder

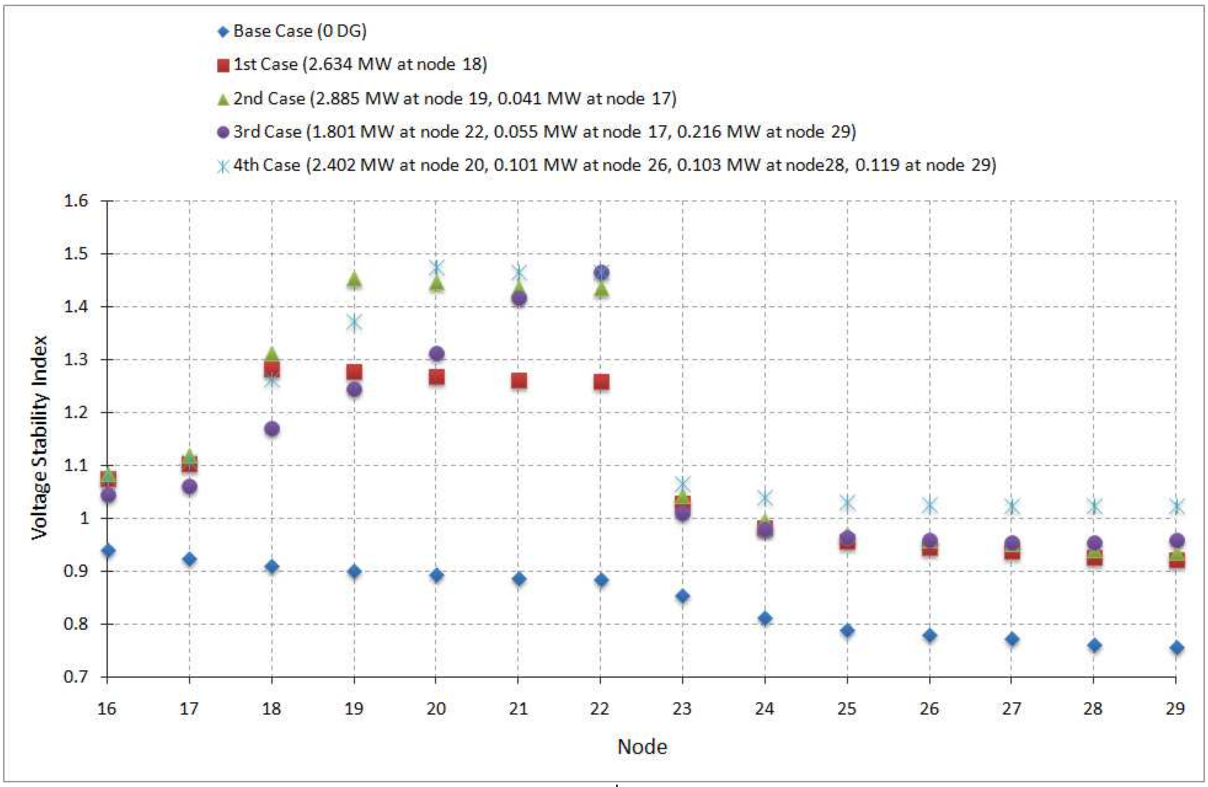

Figure 3 - 4: Voltage stability of the 2nd feeder with integration of DG units

- ***The third feeder***

Figure 3-5 represents the results for the 3rd feeder. It can be seen that the voltage stability improvement in the 2nd, 3rd and 4th cases are approximately the same (while 1.823, 1.926 and 1.944 MW are integrated respectively). The reason behind this is that the large value of the DG power placed at node No. 38 while very small capacities placed at node No. 40 and node No. 42 for the 3rd and 4th cases, respectively. The 1st case is different compared to the other cases because of the low DG power located at the same node (node No. 38).

- ***The fourth feeder***

The enhancement of voltage stability of the 4th feeder for different cases is shown in Fig. 3-6. The voltage stability is enhanced at the 3rd and 4th cases better than the 1st case, although the DG power at the 1st case is 4.028 MW which is approximately twice the DG power (2.156 MW) at the 4th case. This means more loads in this feeder can be added with low DG power integration.

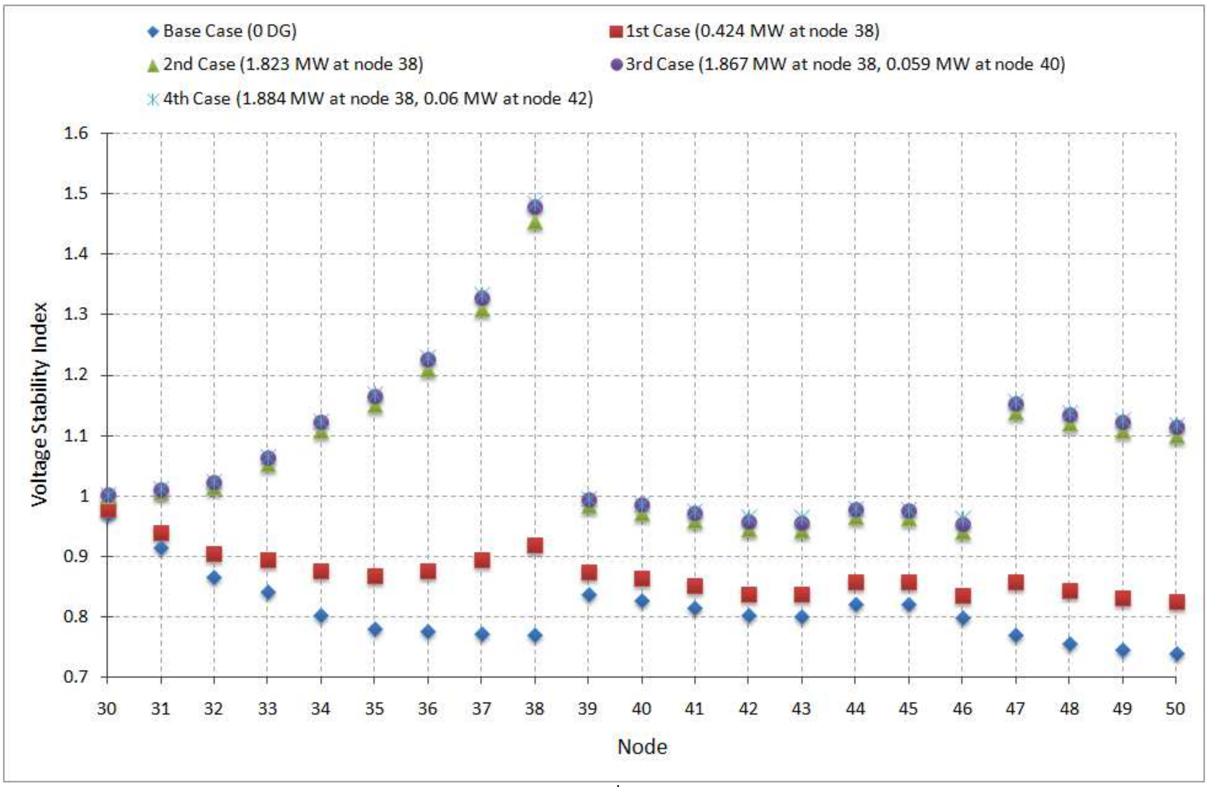

Figure 3 - 5: Voltage stability of the 3rd feeder with integration of DG units

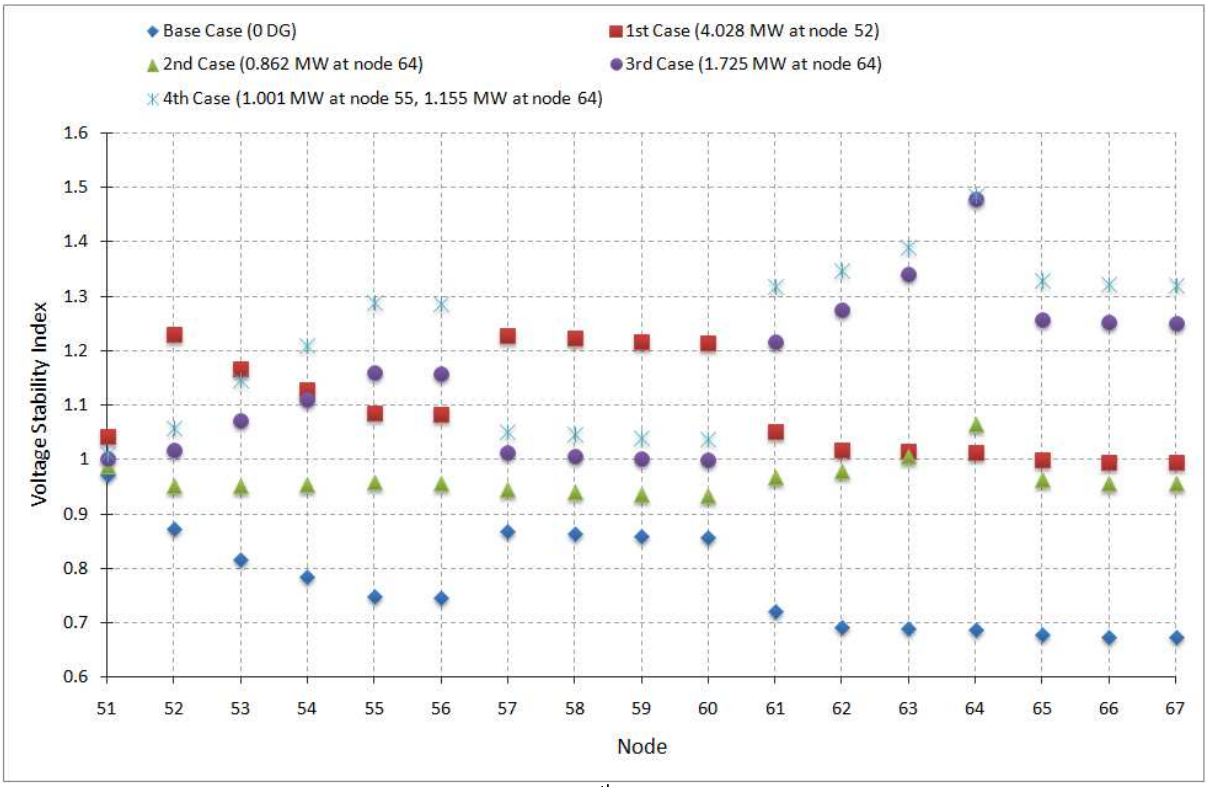

Figure 3 - 6: Voltage stability of the 4th feeder with integration of DG units

3.2 Loadability Evaluation Using Continuation Power Flow

In the previous part the voltage stability is assessed through the evaluation of a voltage stability index. In this part the influence of DG on two different loadability aspects, namely; VLL and VSLL is investigated (classification of these aspects will be presented in the following sections). The loadability regarding the two aspects is evaluated using CPF which implemented in PSAT. The evaluation is conducted on two case studies. The impact of injecting reactive power into the network on the losses is also analyzed. A brief introduction on CPF will be presented first, and then the two test cases with their results are discussed.

3.2.1 Continuation power flow

The continuation method is a mathematical path-following methodology used to solve systems of nonlinear equations. Using the continuation method, a solution branch can be tracked around the turning point without difficulty. This makes the continuation method quite attractive in approximations of the critical point in a power system. The CPF captures this path-following feature by means of a predictor-corrector scheme [Ajjarapu,2006]. Moreover, CPF can be used to determine generator reactive power limits, voltage limits and flow limits of transmission lines [Ajjarapu et al.,1992]. Bifurcation analysis requires steady state equation of power system models, as follows [Milano,2007]:

$$\dot{X} = 0 = f(x, y, \lambda) \qquad (3.17)$$
$$0 = g(x, y, \lambda)$$

Where x are the state variables, y are the algebraic variables (voltage amplitudes and phases) and λ is the loading parameter, i.e. a scalar variable which multiplies generator and load directions as follows:

$$P_G = (\lambda + \gamma K_G)P_{G0} \qquad (3.18)$$
$$P_L = \lambda P_{L0} \qquad (3.19)$$
$$Q_L = \lambda Q_{L0} \qquad (3.20)$$

In Eqs. (3.18), (3.19) and (3.20)P_{G0},P_{L0}, and Q_{L0} are the base case generator and load powers. K_G is the distributed slack bus variable, and γ is the generator participation coefficient. The CPF method implemented in PSAT [Milano,2005] consists of a predictor step realized by the computation of the tangent vector and a corrector step. The corrector step can be obtained either by means of a local parameterization or perpendicular intersection [Milano,2007].

- ***Predictor step [Milano,2007]***

At generic equilibrium point P, the following relation applies:

$$g(y_p, \lambda_p) = 0 \implies \left.\frac{dg}{d\lambda}\right|_p = 0 = \nabla_y g|_p \left.\frac{dy}{d\lambda}\right|_p + \left.\frac{\partial g}{\partial \lambda}\right|_p \tag{3.21}$$

The tangent vector can be approximated by:

$$\tau_p = \left.\frac{dy}{d\lambda}\right|_p \approx \frac{\Delta y_p}{\Delta \lambda_p} \tag{3.22}$$

From Eqs. (3.21) and (3.22) one has:

$$\tau_p = -\nabla_y g|_p^{-1} \left.\frac{\partial g}{\partial \lambda}\right|_p \tag{3.23}$$

$$\Delta y_p = \tau_p \Delta \lambda_p \tag{3.24}$$

A step size control k has to be chosen for determining the increment Δy_p and $\Delta \lambda_p$, along with a normalization to avoid large step when $|\tau_p|$is large:

$$\Delta \lambda_p = \frac{k}{|\tau_p|} \tag{3.25}$$

$$\Delta y_p = \frac{k\tau_p}{|\tau_p|} \tag{3.26}$$

Where $k = \pm 1$, and its sign determines the increase or the decrease of λ. Fig. 3-7 presents a pictorial representation of the predictor step.

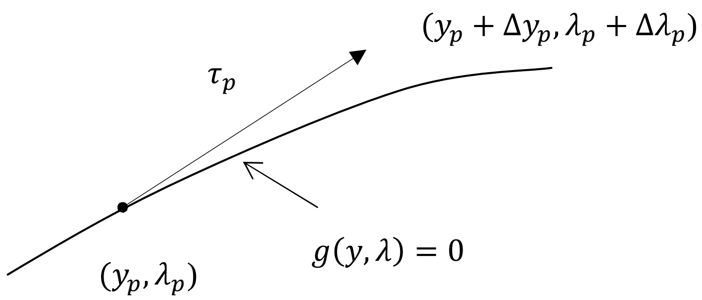

Figure 3 - 7: Predictor step by means of tangent vector

- ***Corrector step [Milano,2007]***

In the corrector step, a set of n+1 equations are solved, as follows:

$$g(y, \lambda) = 0 \tag{3.27}$$

$$\rho(y, \lambda) = 0 \tag{3.28}$$

Where the solution of g must be in the bifurcation manifold and ρ is an additional equation to guarantee a non-singular set at the bifurcation point. Based on the choice of ρ, there are two options: the perpendicular intersection and the local parameterization. In case of perpendicular intersection, whose pictorial representation is presented in Fig. 3-8, the expression of ρ becomes:

$$\rho(y,\lambda) = \begin{bmatrix} \Delta y_p \\ \Delta\lambda_p \end{bmatrix}^T \begin{bmatrix} y_c - (y_p + \Delta y_p \\ \lambda_c - (\lambda_p + \Delta\lambda_p \end{bmatrix} = 0 \tag{3.29}$$

While for local parameterization, either the parameter λ or a variable y_i is forced to be a fixed value.

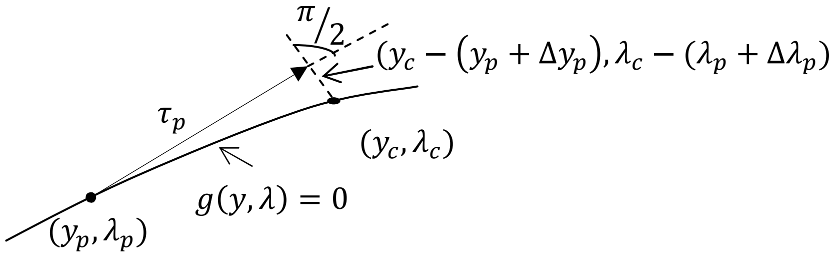

Figure 3 - 8: Corrector step obtained by means of perpendicular intersection

3.2.2 Models of distribution network components

The following steady state models are used:

- The transmission system is modeled as infinite node.
- The distribution lines are modeled by a general series model containing resistance and reactance.
- The load is modeled as a constant PQ component.
- The DG is modeled as a PQ generator. This means that the DG will operate at a constant power factor. In this part of the study the DG is operated at unity, 0.9, 0.8 power factors, where for the last two scenarios the DG can inject reactive power into the system.

3.2.3 Penetration level

The penetration level (PL) can be calculated as a function of the total DG power generation (P_{DG}) over the demand load (P_{Load}) [González-Longatt,2007]

$$PL = \frac{P_{DG}}{P_{Load}} \times 100\% \tag{3.30}$$

3.2.4 First case study

The 15-node distribution network [Das et al.,1995] which is used as the first case study is depicted in Fig. 3-9. It is a balanced three phase radial distribution system consists of 15 nodes and 14 segments, operating at 11 kV. It is assumed that all the loads are fed from the substation located at node No. 1. The system has 14 loads totaling 1.23 MW and 1.25 Mvar, real and reactive power loads; respectively. The data of the system are illustrated in the Appendix A. The load is taken to represent the maximum power at each node which can be simultaneously consumed. The colors of the load are used to identify the loads with the same value. For example, the red color represents the loads of 200 kVA. Figure 3-10 shows the voltage profile of the base case of this system. For each simulation the DG is integrated at one single node starting with node No. 2 up to node No. 15. The PL are varied from 10% over 30%, 50%, and 70% up to 100%. The power factor is also changed from 1.0 over 0.9 to 0.8. The voltage limit for the studied system is taken as ±10% from the nominal voltage. Newton-Raphson load flow method and the CPF method are used to evaluate the losses and loadability of the test system respectively. All the results presented in this part are produced using PSAT [Milano,2005].

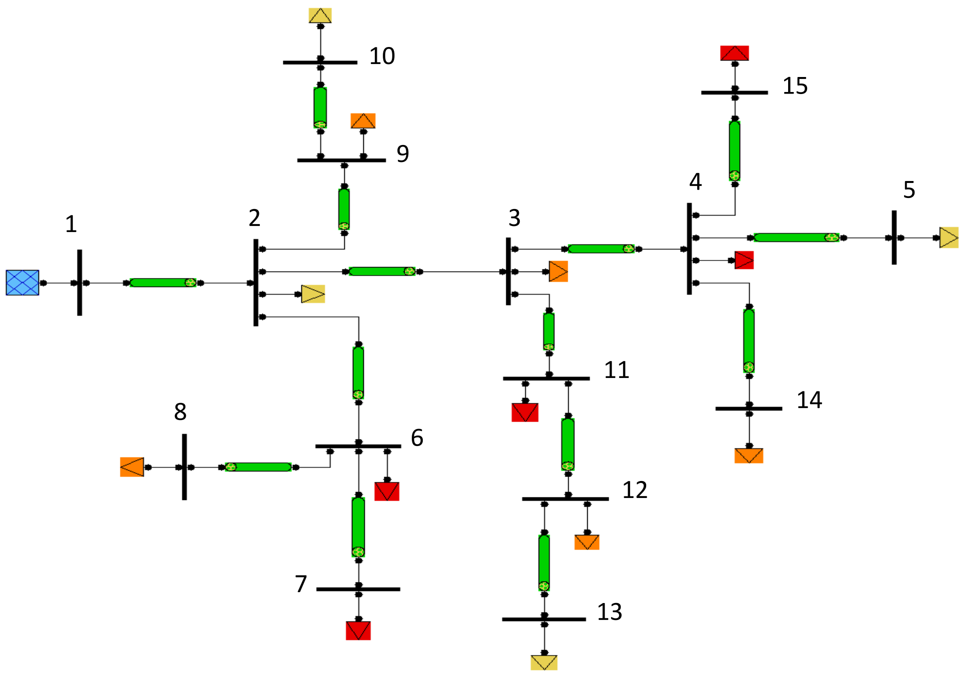

Figure 3 - 9: Test system in PSAT space of the 1st case study

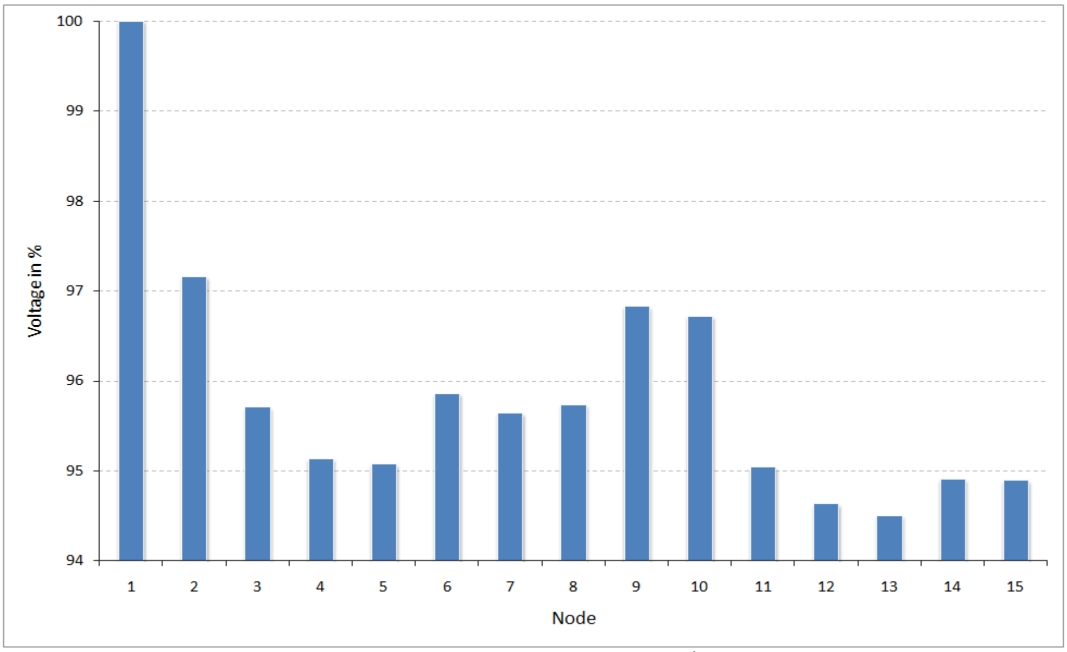

Figure 3 - 10: Voltage profile for the 1st case study

3.2.5 Results of the first case study

- ***Voltage Limit and Voltage Stability Limit Classification***

To demonstrate the two loadability aspects (VSLL and VLL), Figs. 3-11 and 3-12 show the loadability according to VSLL and VLL of the test system as two examples, respectively. Figure 3-11 shows the static voltage stability limit of some selected nodes (node No. 11, 12, 13, 14, and 15) while the load increased by λ (loading parameter) and a DG is integrated at node No. 13 with 30% PL and 0.9 power factor. The maximum loading parameter (λ_{max}) of the studied system without DG is 5.5. It can be seen that this value becomes 5.8 with the integration of DG. Therefore, integration of DG into distribution networks enhances the voltage stability margin with 6% in this case. Figure 3-12 illustrates the voltage profiles of the same nodes with the existence of DG at node 13 while the load is increased until the voltage at one node reached the minimum voltage limit, i.e. -10% of the nominal voltage. The maximum loading parameter according to the voltage limit of the system without DG is 1.7. This value becomes 2.1 with the integration of DG at node No. 13 with 30% PL. Therefore, in the normal operation mode, integration of DG at node No. 13 with 30% PL increases the VLL by 20%. As a result the system can be loaded by 430 kW and 439 kVAr more than the base case (without DG).

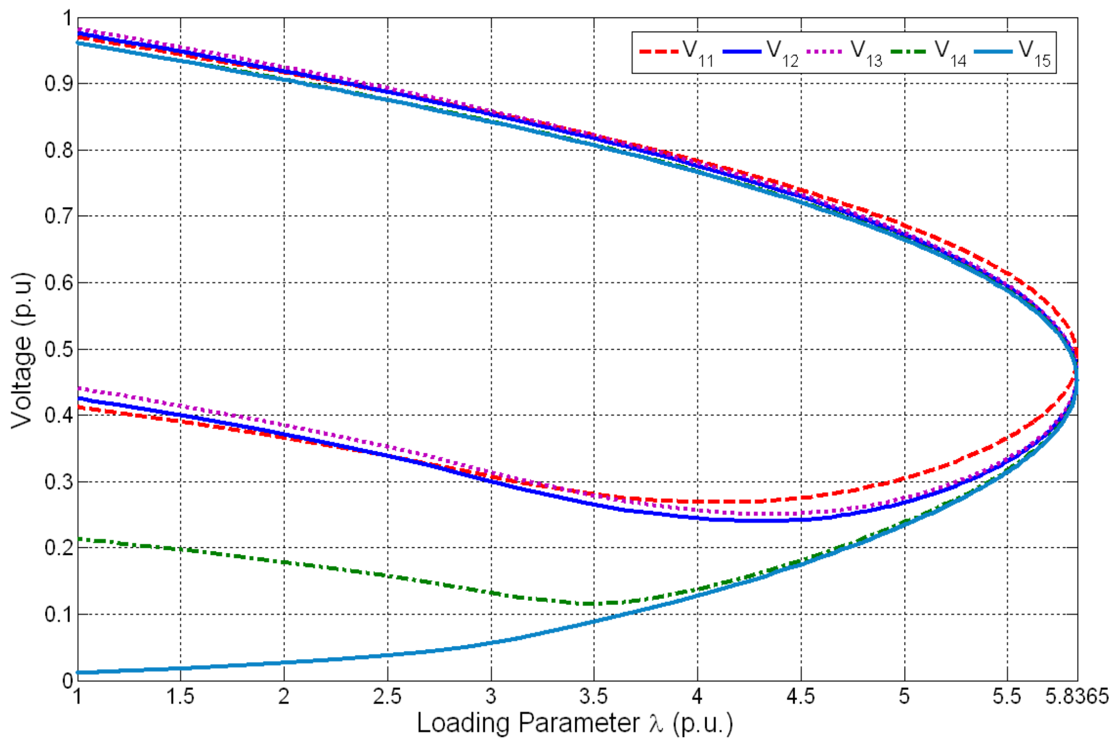

Figure 3 - 11: Steady state voltage stability at some nodes with the integration of DG at node No. 13 with 0.9 power factor and 30% PL

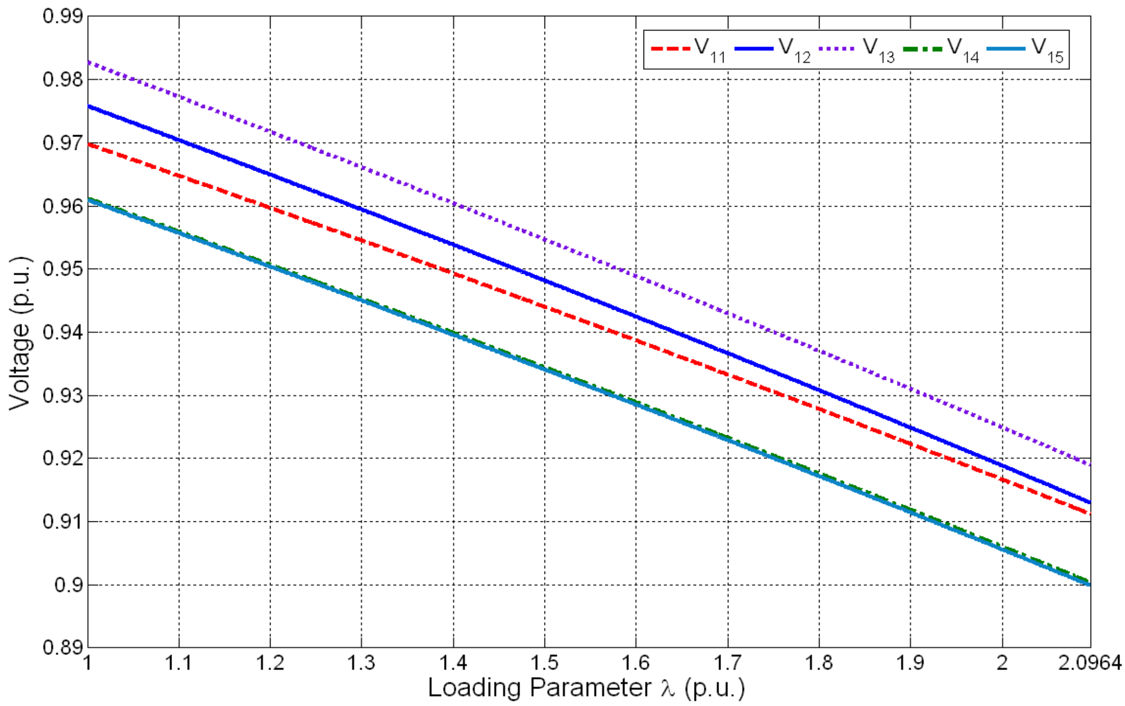

Figure 3 - 12: Voltage profile of some nodes with integration of DG at node No. 13 with 0.9 power factor and 30% PL

- ***Voltage limit loadability***

Figure 3-13 shows the maximum loading in MW according to the voltage limit with integration of different PLs of DG with different reactive power injections. It can be noticed that for 10% PL the VLL is approximately the same with different reactive power supplied from the DG unit. Moreover, integration of a DG unit of 10% PL at each node enhance the VLL approximately with same level except at nodes No. 11, 12, and 13. As the PL is increased from 30%, over 50% to 100% the influence of supplying more reactive power on increasing the VLL can be clearly noticed. It can be seen that as the PL increases the priority of the optimal location, for maximizing VLL, changing within the weakest area of nodes No. 11, 12 and 13 takes place. For example at 10% PL node 13 is the optimal location while at 30 and 50% PLs nodes No. 11, 12 and 13 give approximately the same VL loadability, and at 100% PLs node No. 11 is the optimal location. The reason behind that is the difference between the loads which are connected at these nodes which have a clear impact on the variation of the total losses according to the integration of DG as can be seen in the losses evaluation subsection.

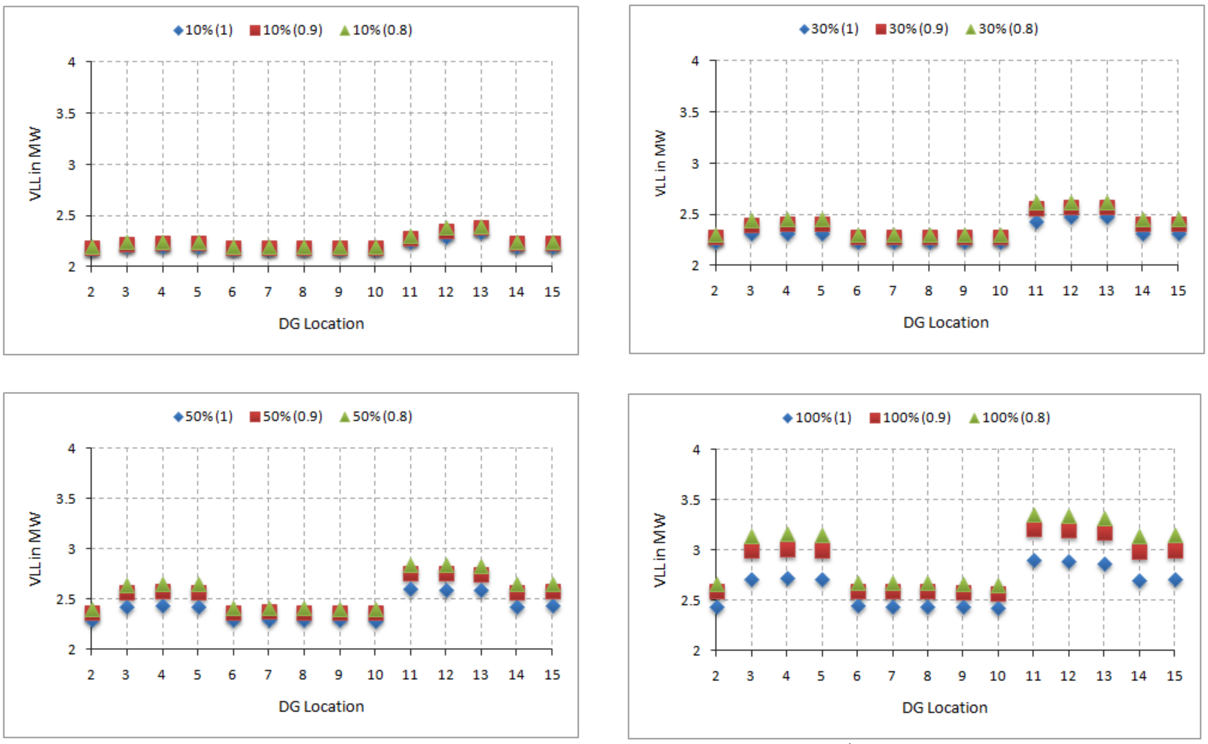

Figure 3 - 13: Maximum loading according to voltage limit for the 1st case study with different penetration level and different reactive power injection

- ***Voltage stability limit loadability***

VSLL is shown in Fig. 3-14 with integration of different penetration levels and different reactive power supplied from DG. It can be inferred from this figure that, for 10% PL the impact of DG integration at each node with different injected reactive powers on the VSLL is approximately the same. The influence of increasing the reactive power injected from the DG units can be clearly noticed as the PL is increased. Comparing Fig. 3-13 to Fig. 3-14 some differences can be seen. For example when the DG is integrated at node No. 11 and node No. 15 the same VSLL is obtained while different VLL is achieved. The reason is the location of these two nodes with respect to the weakest node (i.e. node No. 13). Moreover, DGs at nodes No. 6, 7, 8, 9, and 10 have different impacts on VSLL while DGs at these nodes have approximately the same impact on VLL.

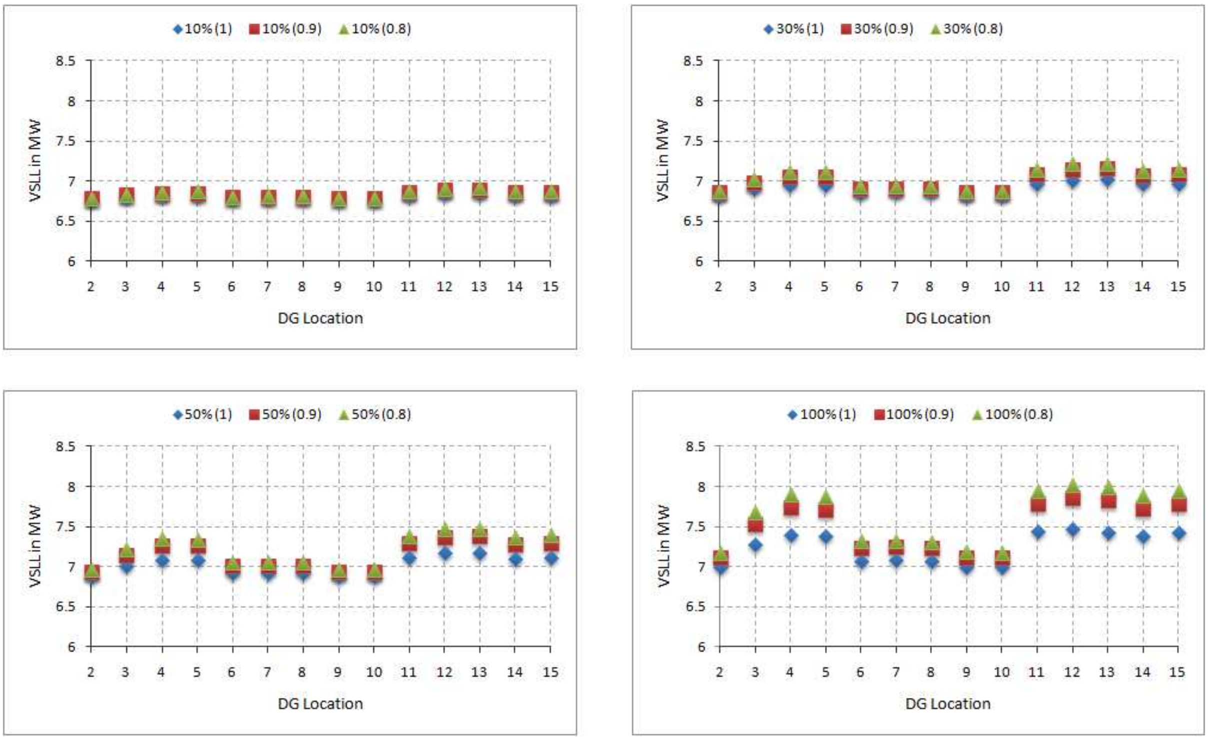

Figure 3 - 14: Maximum loading according to voltage stability limit for the 1st case study

- ***Maximum enhancement***

The maximum enhancements in percentages for the VLL and VSLL with different PLs and different supplied reactive power from the DG unit are given in Fig. 3-15. These values have been evaluated using the maximum value of λ among different values obtained by integrating the DG at each node. Then the maximum improvement can be evaluated relative to VLL of the base case. It can be clearly inferred that the VLL is improved more than the VSLL even in the case of the unity power factor DG operation scenario. The difference in the enhancement between the VLL and VSLL is increased as the PL is increased for each operation scenario. For example, at 10% and 50% PL with unity power factor operating scenario, the differences between the percentage improvement in VLL and VSLL are 7.6% and 15.2%, respectively. Furthermore, the difference in the improvement increases as the supplied reactive power is increased. For example, the differences are 15.2% and 19.3% for 50% PL with unity and 0.9 power factors, respectively. That means regarding to the normal operation the network operator can achieve more loadability benefits with the interconnection of DG units.

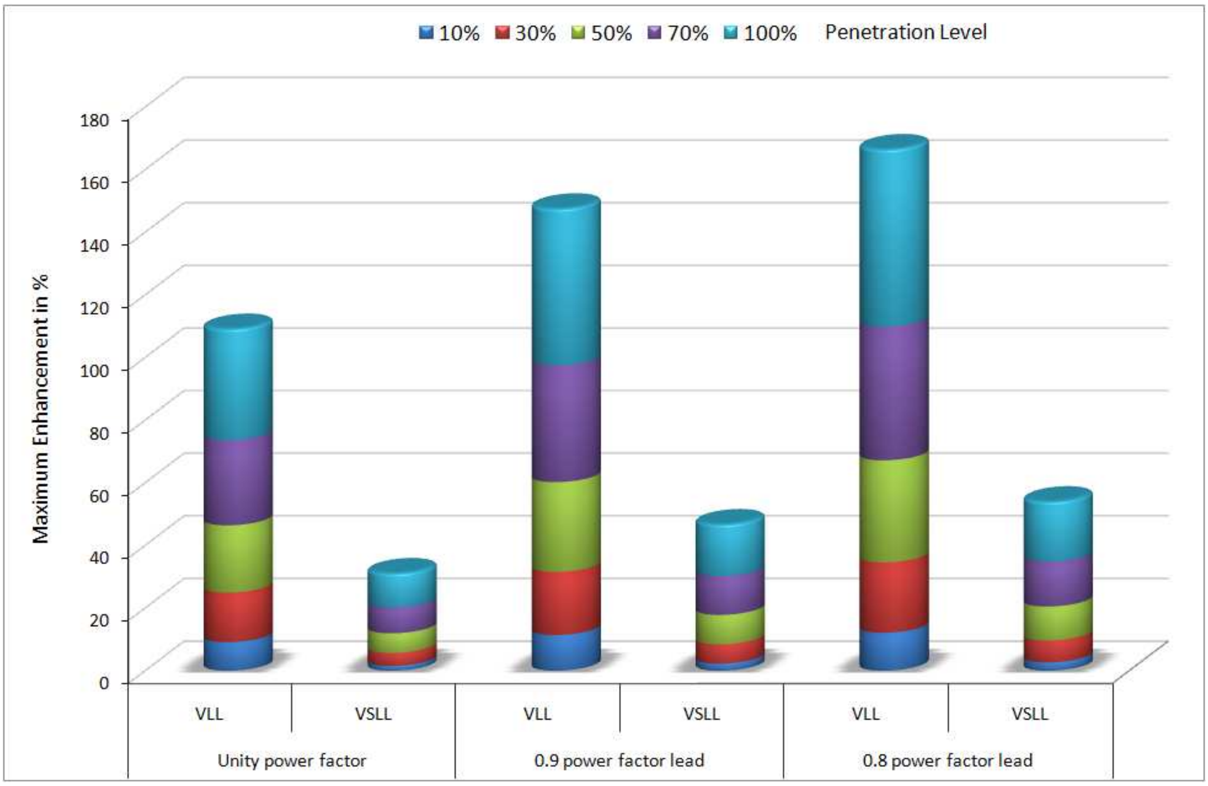

Figure 3 - 15: Maximum enhancement in VLL and VSLL with different PLs and different Q injections

- ***Losses***

Power losses can be divided into two categories: real power loss and reactive power loss. The resistance of the lines causes the real power loss, while reactive power loss is produced due to the reactive element. Normally, the real power loss draws more attention for the utilities as it reduces the efficiency of transmitting energy to customers. Nevertheless, reactive power loss is obviously not less important, due to the fact that reactive power flow in the system needs to be maintained at a certain amount for sufficient voltage level. Consequently, reactive power makes it possible to transfer real power through transmission and distribution lines to customers [Ramesh et al.,2008].

The active power losses and reactive-voltage-drop (reactive power loss) of the system with integration of DG at every node are evaluated using Newton-Raphson load flow method. The evaluation is conducted to demonstrate ***the effect of increasing the reactive power*** injections from the DG at different PLs on the losses of the network.

Figures 3-16 and 3-17 show the active and reactive power losses, respectively. It can be seen that at low PL (e.g. 10%) the losses trend looks approximately like the voltage profile of the base case of the studied system. It can be inferred also that as the reactive power injection from DG increases the losses decrease at PLs 10, 30, and 50%. As the reactive power injection from the DG increases over a certain limit (e.g. 70 and 100% PLs) the losses are increased, decreased, or still the same. Moreover, it can be observed that at each node there is a certain DG capacity which gives the minimum losses. That is clear for nodes No. 10, 12, and 13 as the power factor of the DG unit is changed from unity to 0.9 the losses are decreased and as the power factor is changed to 0.8 the losses is increased again. This means that control the reactive power injected into the system from the DG has an impact of the network loss.

From Fig. 3-17, it can be inferred that a small difference between the impact of DG on the active and reactive power losses can be observed. For example, at 100% penetration level and unity power factor at nodes No. 7, 8, and 9, the active power losses start to increases while reactive power is still decreasing.

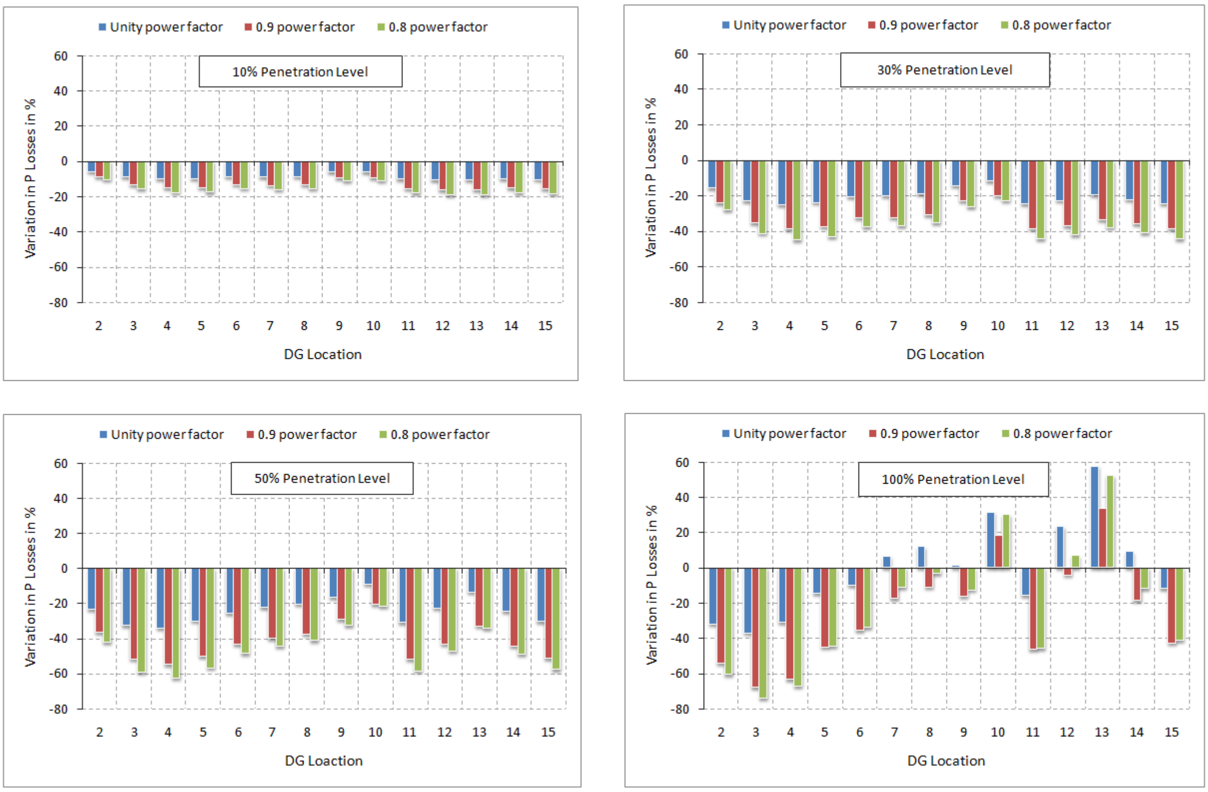

Figure 3 - 16: Variation in real power losses in percentage

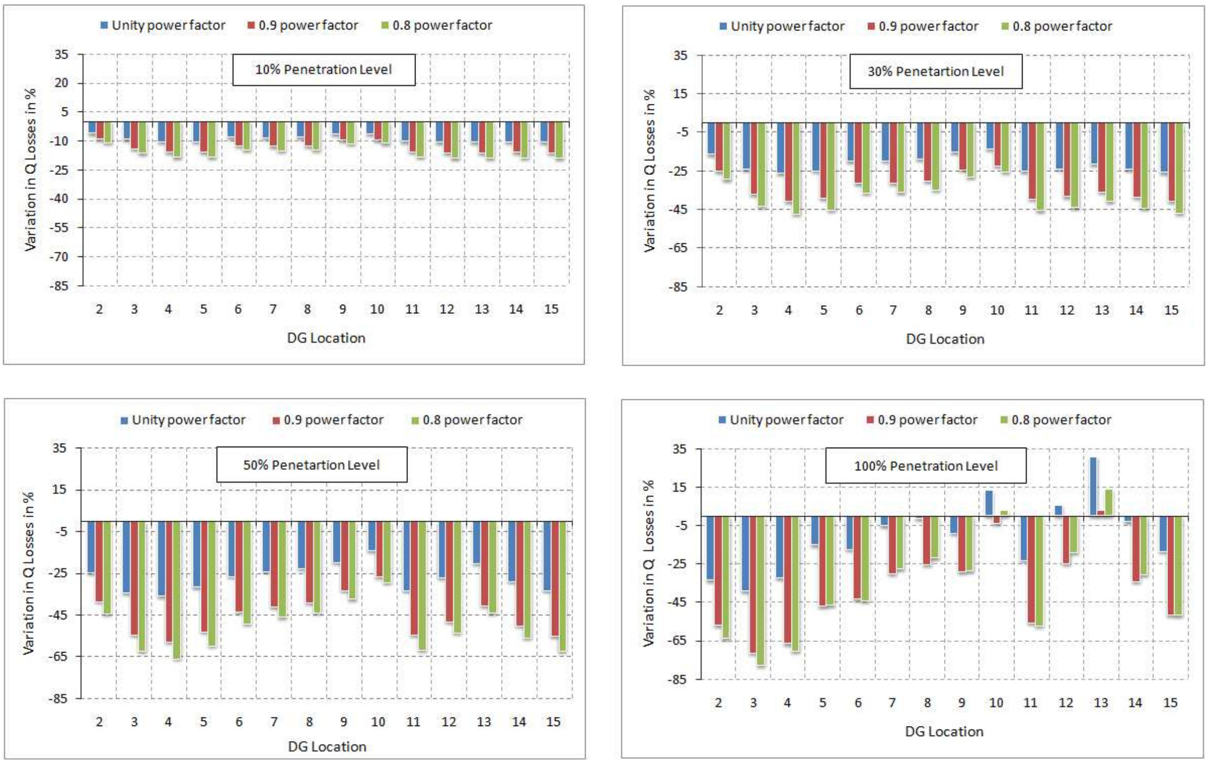

Figure 3 - 17: Variation in reactive power losses in percentage

3.2.6 Second case study

Figure 3-18 shows the one line diagram of the second 15 node system [Li et al.,2000]. It operates at 6.6 kV voltage level. The system has 14 loads totaling 6.229 MW and 2.624 Mvar, real and reactive power loads, respectively. The line and load data of the system are given in the Appendix A. There are different sizes of shunt capacitors connected at different nodes of this system. From Table A3 in the Appendix A, it can be observed that the power factor of all loads is approximately 0.99 except the load at node No. 11. Moreover, the load at that node represents approximately 35% and 85% of the total active and reactive power load of the system, respectively. The lateral which contains nodes No. 7, 8, 9, 10 and 11 supplied approximately 57% and 90% of the total active and reactive power load of the system, respectively.

Voltage profile of the base case of the system is shown in Fig. 3-19. It can be concluded that the 2nd case study network is more heavy loaded when it is compared with the 1st case study network. That can be clearly concluded from the results illustrated in Table 3-2. The difference between VSLL and VLL of the 1st case study is 2.4 times the difference of the 2nd case study.

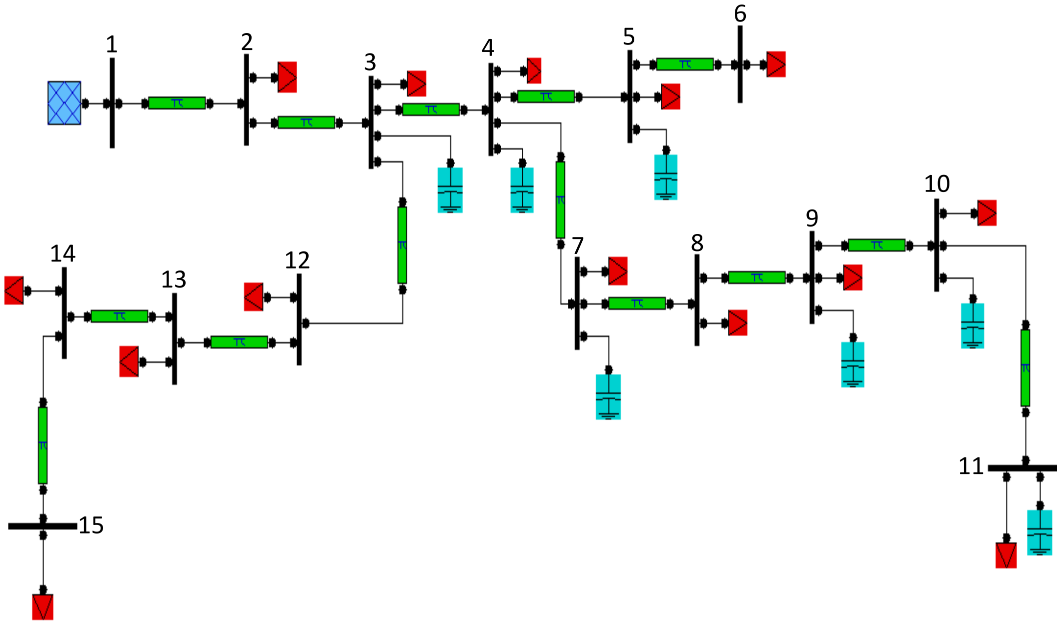

Figure 3 - 18: Network in PSAT space of the 2nd case study

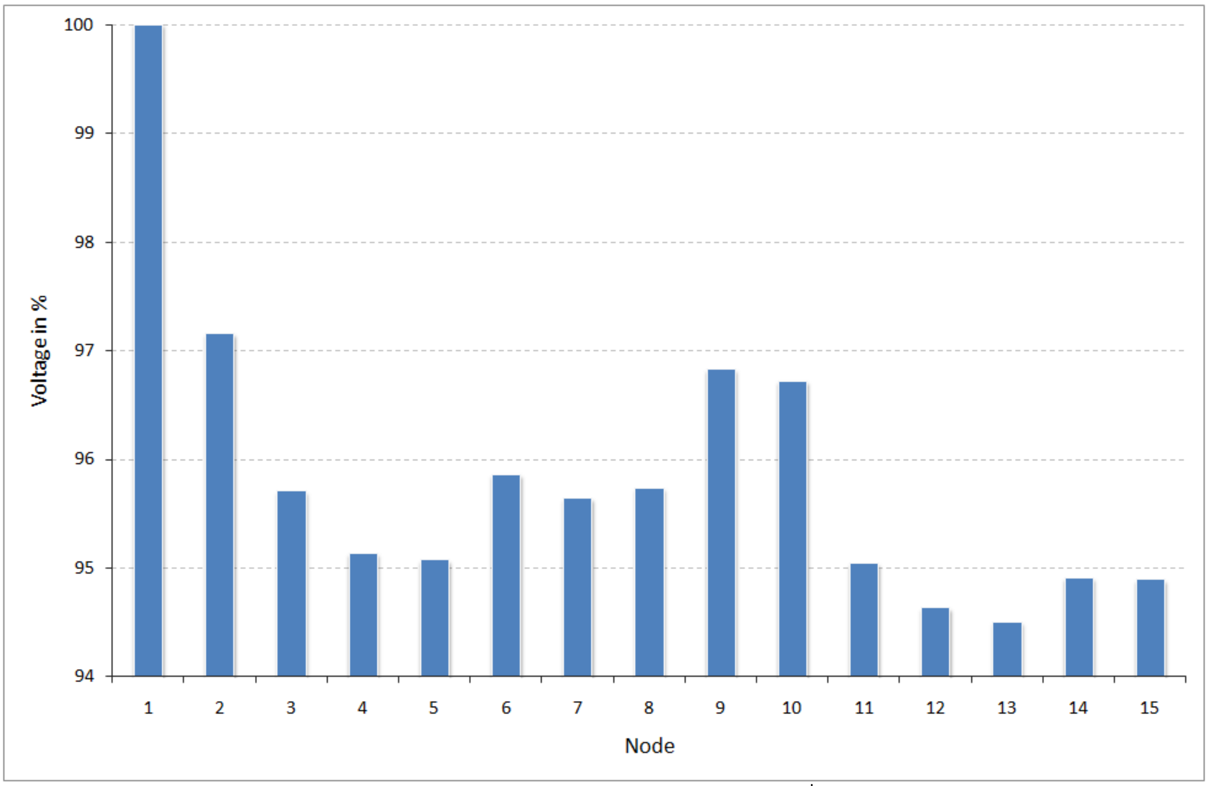

Figure 3 - 19: Voltage profile of the base case for the 2nd case study network

Table 3 - 2: λ_{max} for VSLL and VLL of the two case studies without DG

	λ_{max} (VSLL)	λ_{max} (VLL)	Difference
1st Case	5.5	1.7	3.8
2nd Case	2.7	1.2	1.6

3.2.7 Second case study results

- ***Voltage limit loadability***

CPF method was used to evaluate the loadability of the 2nd case network with respect to the two aspects. The maximum loadings in MW according to the VLL with integration of DG at each node with 100% PL and different reactive power injections are shown in Fig. 3-20. It is clear that integrating DG at node No. 11 has a significant impact on the voltage limit loadability, and this is because the high load connected at that node. It can be seen that integration of DG without reactive power (i.e. at unity power factor) has low impact in increasing the VLL when it compared to the 1st case results. The reason behind this is the low power factor of the load at node No. 11 (0.702 lag). Therefore as the reactive power increases the VLL loadability increases more than the first case especially when the DG is integrated at the weakest area. The results for all penetration levels are shown in Fig. B-1 in the Appendix B.

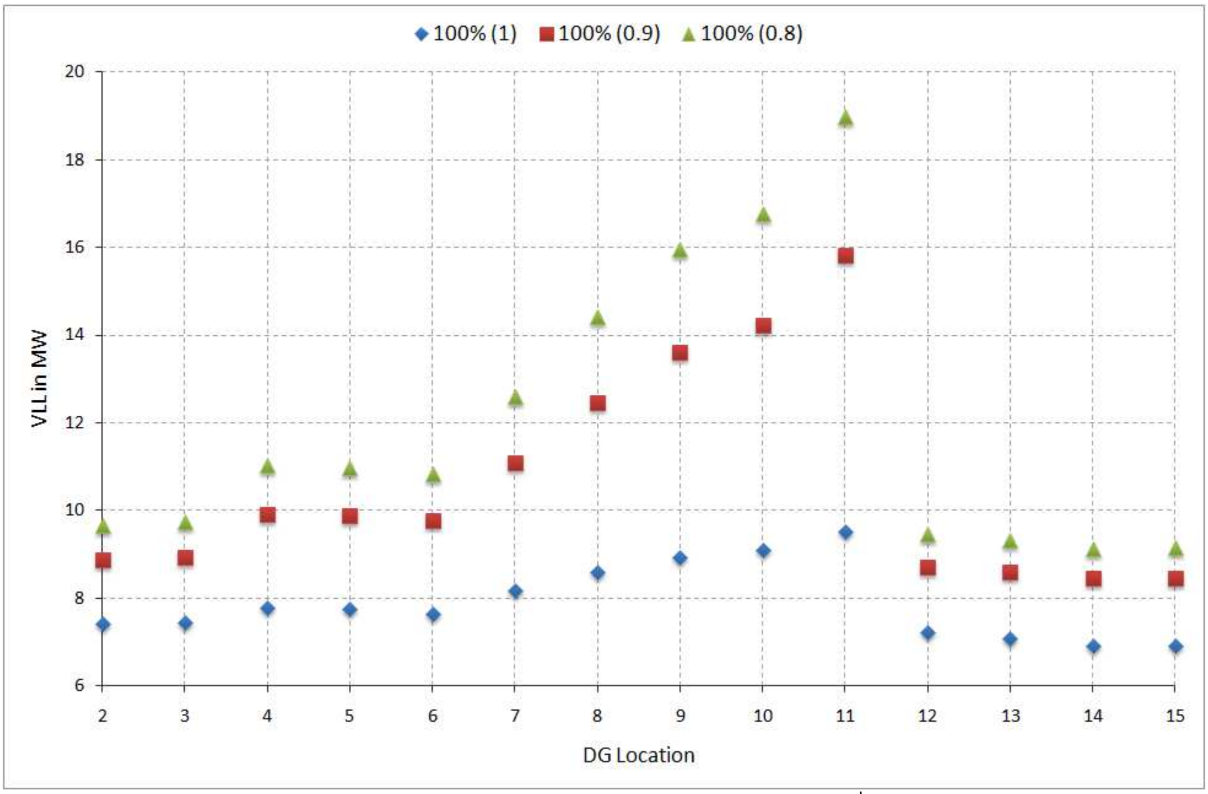

Figure 3 - 20: Maximum loading according to voltage limit for the 2ndcase study with 100% PL

- ***Voltage stability limit loadability***

The influence of DG integration with 100% PL on the VSLL of the network is evaluated and presented in Fig. 3-21. The results for all penetration levels are given in Fig. B-2 in Appendix B. As excepted integration of DG units at the heavy loaded node in the network improve the VSLL, especially when reactive power is injected from the DG. For example, for 50% DG penetration level with different power factors at node No. 11, the VSLL is increased from 17 MW to 19.53, 21.9, and 23.2 for unity, 0.9, and 0.8, power factors, respectively. This means that the VSLL is enhanced in this case by 15, 29, 36.5% for unity, 0.9 and 0.8 respectively. It can be demonstrated that the enhancement with 0.8 power factor in that case is more than twice of the enhancement with unity power factor. That is because the poor power factor of the heavy load connected at node No. 11. Moreover, although the same active power is supplied through the DG unit, the reactive power to be consumed at that node is supplied by the main station in the case of unity power factor. In the other side, if the DG supplied reactive power then a large part of the required reactive power is locally consumed and therefore, the VSLL will be highly improved.

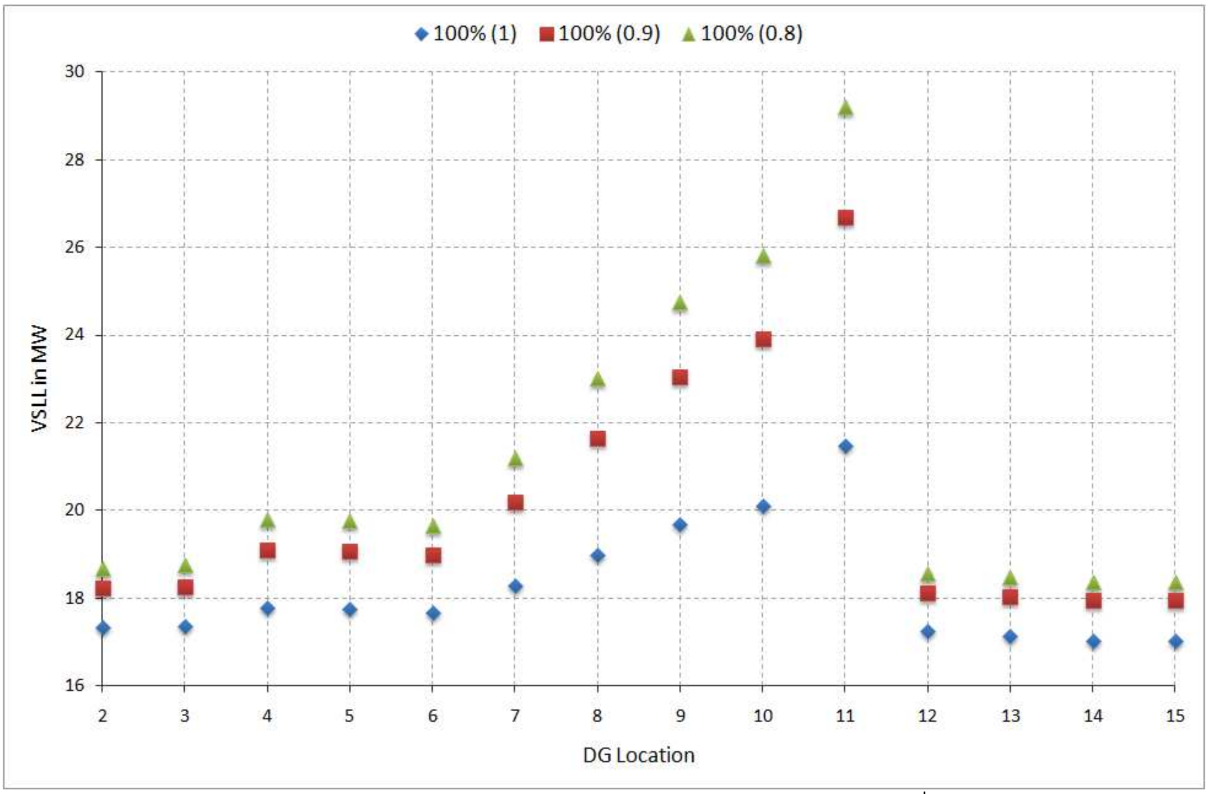

Figure 3 - 21: Maximum loading according to voltage stability limit for the 2nd case study with 100% PL

- ***Maximum Enhancement***

A comparison between the maximum improvement in VLL and VSLL for different PLs and different reactive power injections is illustrated in Fig. 3-22. It can be observed clearly from this figure that the difference between the enhancement of VLL and VSLL with integrating DG with unity power factor is not high compared to the cases with reactive power. For example, the difference in the improvement of VLL and VSLL for 50% PL with unity and 0.9 power factors are 5%, and 31.6%, respectively. This case study illustrates a special case, while a large load is connected at node No. 11, which represents 35% and 84% of the total active power, and reactive power respectively. Therefore, supplying reactive power at that node even small amount will have a significant impact on the improvement of VLL and VSLL.

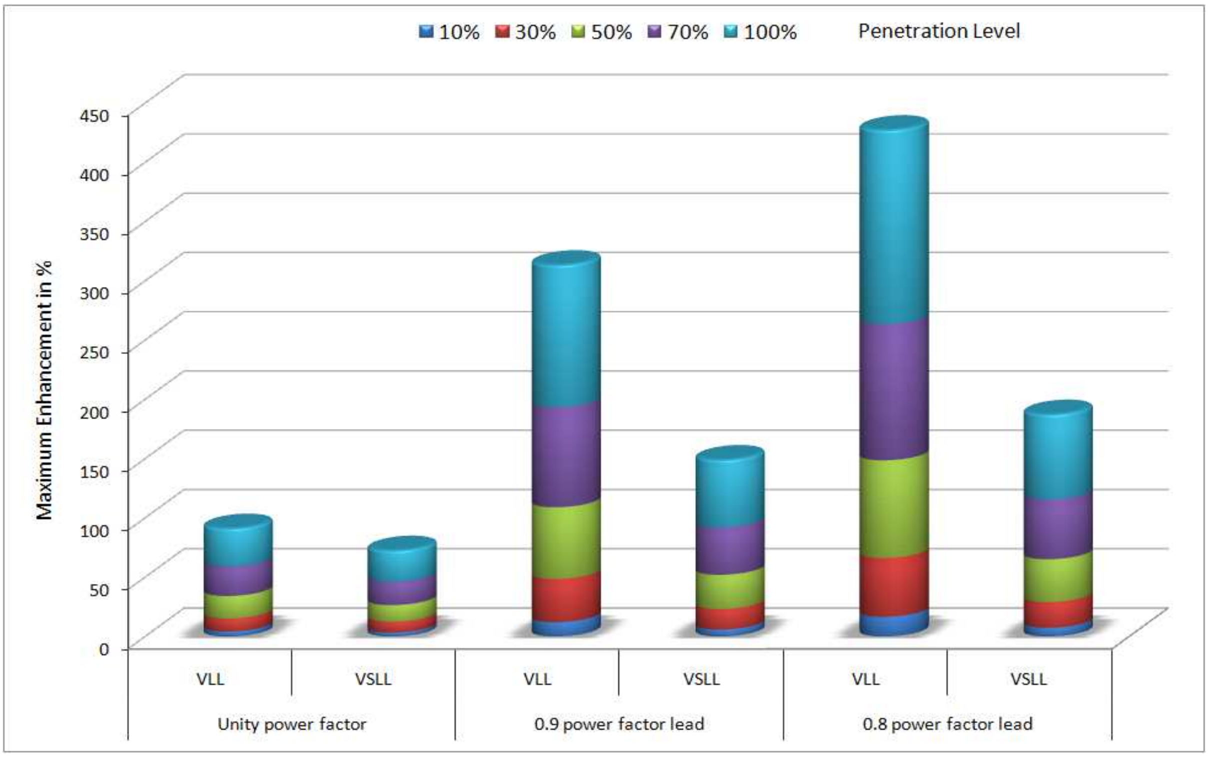

Figure 3 - 22: Maximum improvement in the two loadability aspects with different PLs and different Q injections for the 2nd case study

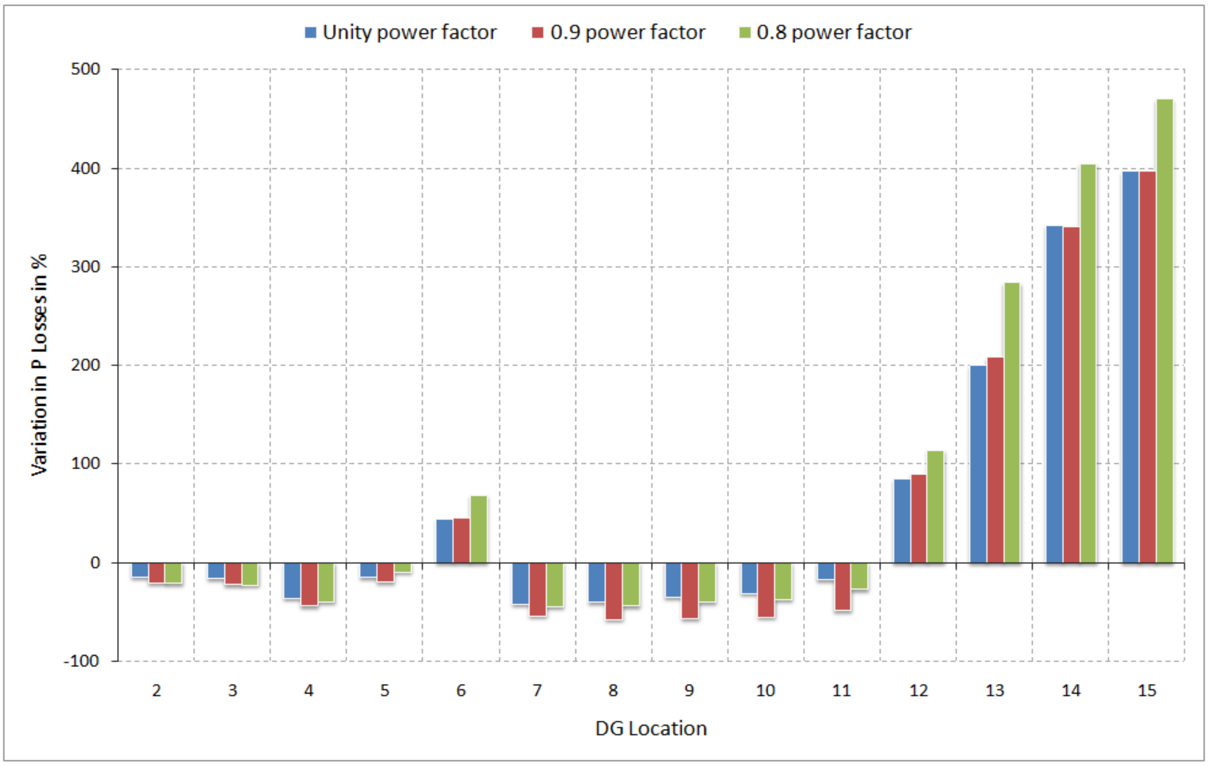

Figure 3 - 23: Variation in active power losses in percentage with 100% PL and different reactive power injections

- ***Losses***

The active and reactive power losses of the 2nd case study network with integration of DG at each node with 100% PL are illustrated in Figs. 3-23 and 3-24, respectively. The results for different penetration levels are given in Figs. B-3 and B-4 in Appendix B. It can be observed that the active power losses are decreased with low PLs (i.e. 10 and 30%) at almost all nodes except nodes No. 14 and 15. As the PL increases more than 50% the reduction percentage is decreased at some nodes. However a very high increase percentage is observed especially at nodes No. 12, 13, 14, and 15. Moreover, as the reactive power increases at this high PL at these nodes the losses are more increased. This can be explained as the power supplied from the DG flows to be consumed at the heavy load point in the system (node No. 11) so, this power flows through a long path increasing the power losses. Moreover, it can be observed from these two figures, that the trend of reactive power losses is different than that of active power losses. The increase percentage in reactive power case is less than that of active power. It can be concluded that in some cases the DG can have a severe impact on the system losses (e.g. the losses increase by 470%) so that each system has to be analyzed and investigated before the integration of DG units. Moreover, injecting reactive power from DG into the distribution network has to be controlled because of its significant impact on the losses.

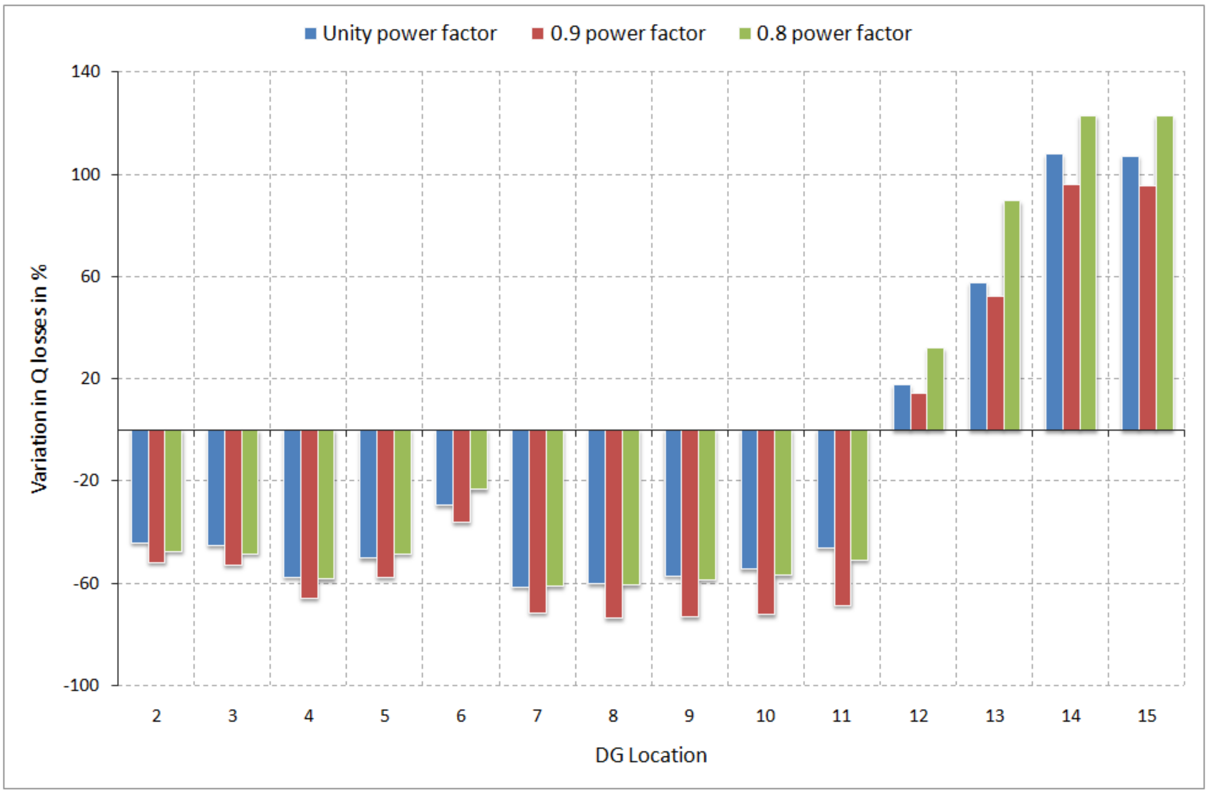

Figure 3 - 24: Variation in reactive power losses in percentage with 100% PL and different reactive power injections

3.3 Summary

This chapter introduced two main parts. The first one presents the implications of the location and the capacity of DG on the voltage stability enhancement of the MV distribution networks. These impacts are evaluated using a previously proposed voltage stability index which can be evaluated at each node of the network. The results showed that dispersing the DG supplied power at different nodes in the network enhances the voltage stability more than concentrating it at a certain node.

In the second part of this chapter the loadability of MV distribution networks was tested according to two aspects. The first aspect is the voltage stability limit loadability (VSLL), while the second is the voltage limit loadability (VLL). The evaluation process was conducted based on continuation power flow (CPF) which is implemented in PSAT. The loadability aspects were tested on two different MV distribution networks by integrating a DG unit at each node of the network with different penetration levels and different reactive power injections but not simultaneously. The first test system represents a MV distribution network operates at 11 kV. This system is not heavy loaded where the voltage profiles of the base case shows a difference of approximately 5% in the voltage between the main station and the far node. The second system operates at 6.6 kV and it can be clearly seen that it is heavy loaded where the load profile of the base case shows a difference of approximately 8.5% between the main station and the far node even the reactive power is compensated through the connection of fixed capacitors. The load at node No. 11 represents a large part of the total load (35% of the total active power) which represents a special case to be investigated. Moreover, the influences of supplying reactive power from the DG on the network losses have been studied.

To highlight the impact of the location on the degree of the improvement in the voltage limit loadability the enhancement related to the base case are evaluated. The VLL of the first case study without DG is 2040 kW. That means all of this consumed power is supplied through the main station. With integration of 100% PL which means that the DG supplies 1200 kW. To approach the same VLL of 2040 kW then 840 kW will be supplied from the main station. However, with the existence of 100% PL the VLL is 2839 kW while the DG is integrated at an optimal location to get the maximum enhancement. That means with the DG (100% PL) the VLL is increased by approximately 800 kW.

From the analysis, the following conclusions can be drawn:

- Integration of the DG into the distribution network enhances the loadability according to the two studied aspects.
- The VLL will be improved more than the VSLL with the existence of DG.
- At low penetration levels, changing the reactive power supplied from the DG unit has no significant impact on enhancing the VLL or VSLL aspects. While for the high PLs, this impact can be clearly observed.
- The optimal location to maximize the loadability, according to VLL aspect, depends on the variation of the penetration level.
- The reactive power should be controlled because it has significant impacts on the system losses.
- At each node of the network there is a certain capacity of the DG for minimizing the losses.
- Each distribution system should be studied in details using different analysis techniques when the DG is intended to be integrated.

CHAPTER 4: EFFICIENT INTEGRATION OF DG FOR MEETING THE INCREASED LOAD DEMAND

The power systems face increasing load demand whereas the network expansion is restricted due to many reasons such as lack of investment or serious concern on the environmental problems [Nakawiro et al.,2008]. The problem of energy consumption increase clearly appears in the developing countries due to a dramatically increase in the population accompanied with an increase in the new investments in the industrial sectors. Installation of DGs in certain locations to meet the increasing demand can reduce or avoid the need for building new transmission and distribution lines and upgrading the existing power systems [El-Khattam et al.,2004]. In the next section a brief overview about the energy consumption in Egypt as one of the developing countries will be introduced.

In this chapter a new methodology for identifying different recommended locations for multi-DG units will be presented. The new methodology is developed based on the CPF method which is implemented in PSAT. Other technical issues like the system losses, voltage profile, and voltage stability margins are also investigated for the resulted DG locations. The proposed methodology is implemented first using a certain number of DG units then using different penetration levels and different reactive power injections of DG units.

4.1 Energy Consumption in Egypt

Egypt as one of the developing countries is the largest economy in North Africa with around 80 million inhabitants, home to almost half the region's population. The electricity sector will require \$36 billion of investment over 2004-2030, with private financing likely to be necessary [IEA,2005]. The analysis introduced in [Trieb et al.,2007] shows that electricity consumption in Egypt will be developed from 70.7 TWh in 2000 to 631.3 TWh in 2050. This means that in 50 years it will be increased by 560.6 TWh as can be seen in Fig. 4-1. This fact can be observed in the development in the peak load as reported in the annual reports of the Egyptian Ministry of Electricity and Energy in [MOEE Website,2010]. It can be inferred that more and more loads have to be supplied in the future and investments in expansion and reinforcement in the existing systems are faced by economical and environmental restrictions. The question which this work in this chapter try to answer is "can DG units provide a part of the solution to face the increasing load demand?" The answer of this question will be concluded from the results.

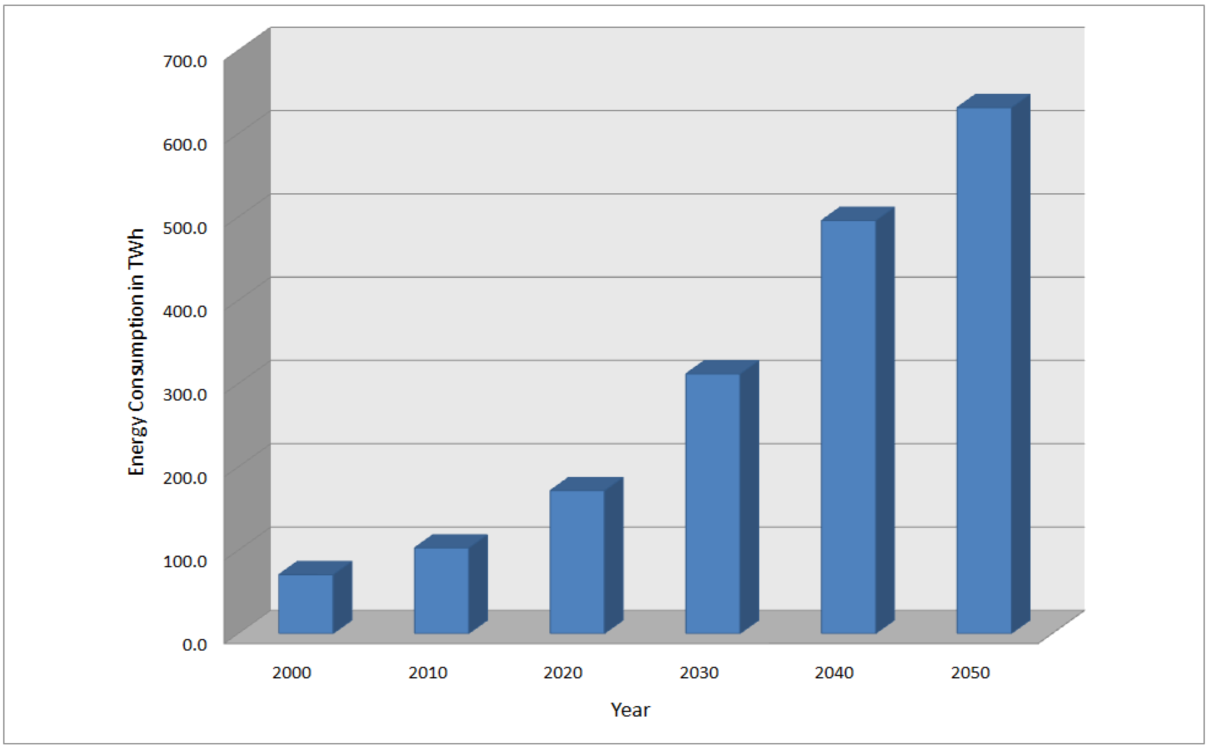

Figure 4 - 1: Electricity demand development in Egypt [Trieb et al.,2007]

4.2 Placement Algorithm

Different recommended locations for integration of DG for increasing the amount of loads which can be supplied from the system through enhancing the VLL of the system are the main objective of the suggested methodology. The proposed algorithm is depicted in Fig. 4-2. The methodology starts with execution of CPF to specify the VLL of the base case of the system and identify the first node which reached the low voltage limit. Then the DG unit with a certain power is integrated at that node and after that the CPF is executed. Therefore, another node can be obtained and then the DG units' power is dispersed between the resulted nodes according to their loads, then the VLL is checked. This process is continued until no improvement is obtained and as a result the methodology will be ended. Different steps of the proposed algorithm are summarized as follows:

Step 1: Identifying the first node reached the low voltage limit in the network using CPF.
Step 2: Integrating the DG units at that node and examine the VLL of the network.
Step 3: Running the CPF with DG.
Step 4: Identifying another node which reached the low voltage limit using CPF.
Step 5: Dispersing the DG power between the recommended nodes according to their loads.
Step 6: Running the CPF with DG.
Step 7: Examining the VLL with the existence of the different number of DG units.
Step 8: Go to step 4 if an improvement in VLL is achieved otherwise go to step 9.
Step 9: End

In the flowchart the PL is specified through the process that is taken into consideration for the second application of the case study.

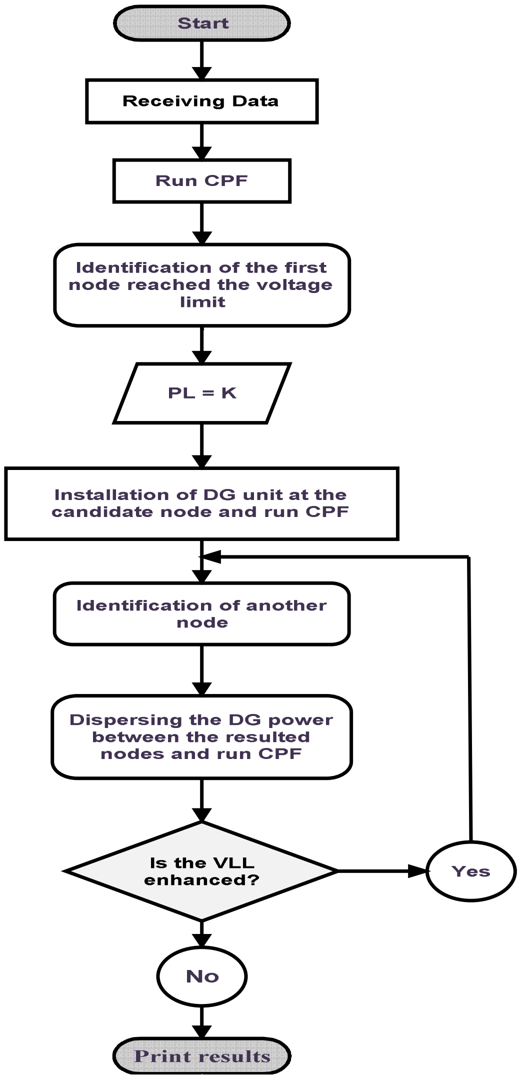

Figure 4 - 2: Flowchart of the proposed methodology

4.3 Case Study

The placement methodology is implemented on a 85 node distribution network [Das et al.,1995] (see Fig. 4-3). The data of the system is given in Appendix C. It is a balanced three phase radial distribution system that consists of 85 nodes and is operated at 11 kV. It is assumed that all the loads are fed from the substation located at node No. 1. The system has 75 loads totaling 1.8 MW and 1.84 Mvar, real and reactive power loads respectively. The VLL of the system without integration of DG is found to be 2073 kW.

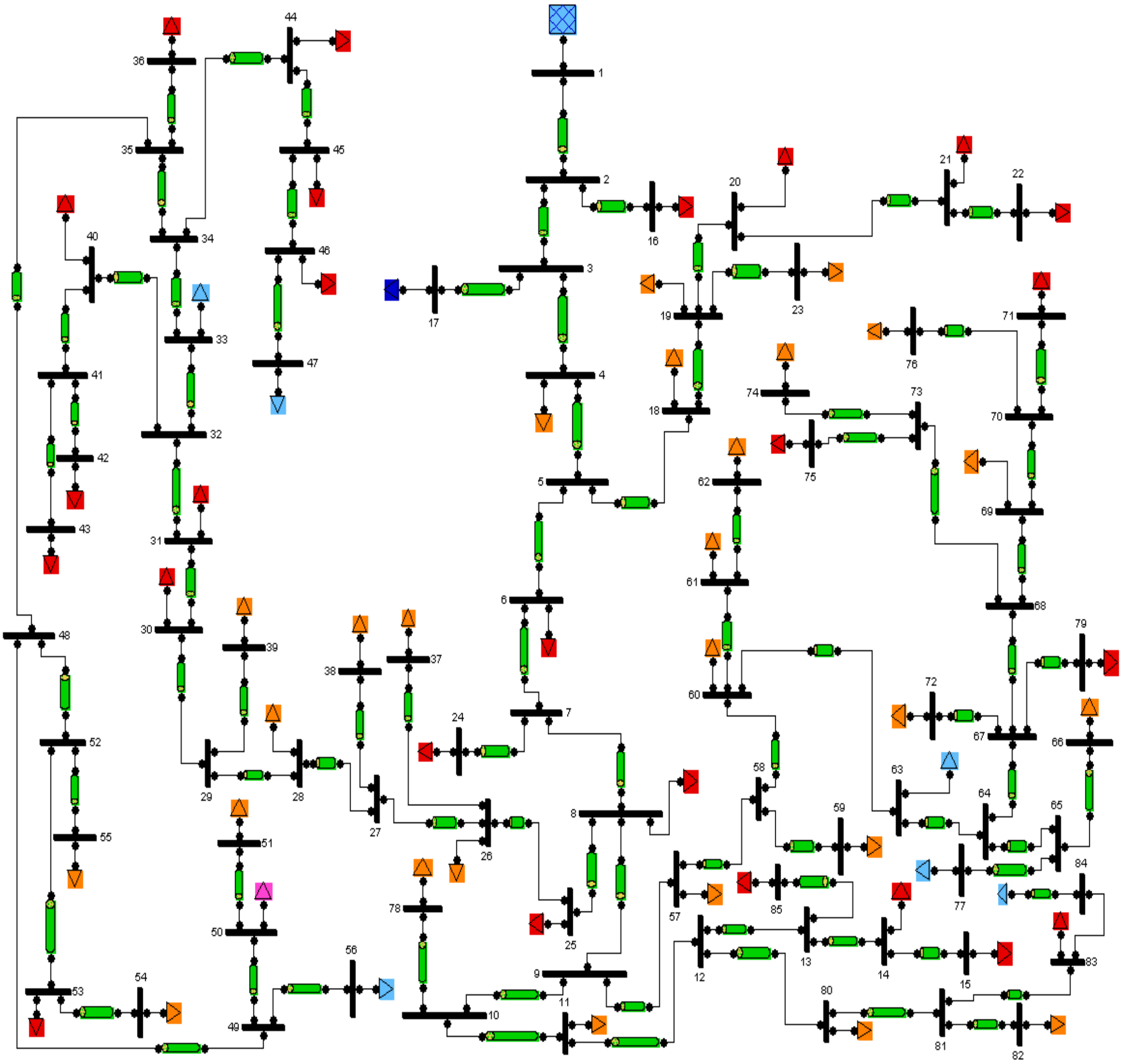

Figure 4 - 3: One line diagram of 85 node distribution network in PSAT space

4.3.1 First application

The suggested placement approach is applied first for 6 × 240 kW, 0.4 kV DG units. Each DG unit is integrated through 0.4/11 kV transformer, which has R = 0.0 p.u., and X = 0.13 p.u. The DG is modeled as a PQ generator operating at 0.9 power factor. This application is performed as an explanation of the procedure of the methodology.

- ***Simulation results***

After the first execution of the CPF, it was found that node No. 54 is the first node reached the low voltage limit. According to the methodology all the DG units are integrated at this node, then the process will be completed until no improvement in VLL can be achieved. The resulted nodes priority and DG power at each node of the studied system are given in Table 4-1.

Table 4 - 1: Recommended nodes priority and DG units number integrated at each node

Iteration No.	Nodes Priority	Number of DG Units Integrated
1	Node 54	6 units
2	Nodes 54 and 76	3 units
3	Nodes 54, 76, and 47	2 units

The results of VLL improvement is depicted in Fig. 4-4. The improvement in percentage is calculated relative to the base case. It can be demonstrated that VLL is improved when the DG power is dispersed between the resulted nodes. A 515 kW is the difference in VLL of the system between integrating two units at each node of the three resulted nodes and integrating the six units at one node. This means that the network can be loaded by 15.7% more than the case of concentrated DG units at node No. 54 while the voltages are kept within the limits. When DG is owned by the electrical utility, then dispersing the DG power at more than one location will be helpful in supplying more loads and postponing the reinforcement of the existing system to meet the increasing demand.

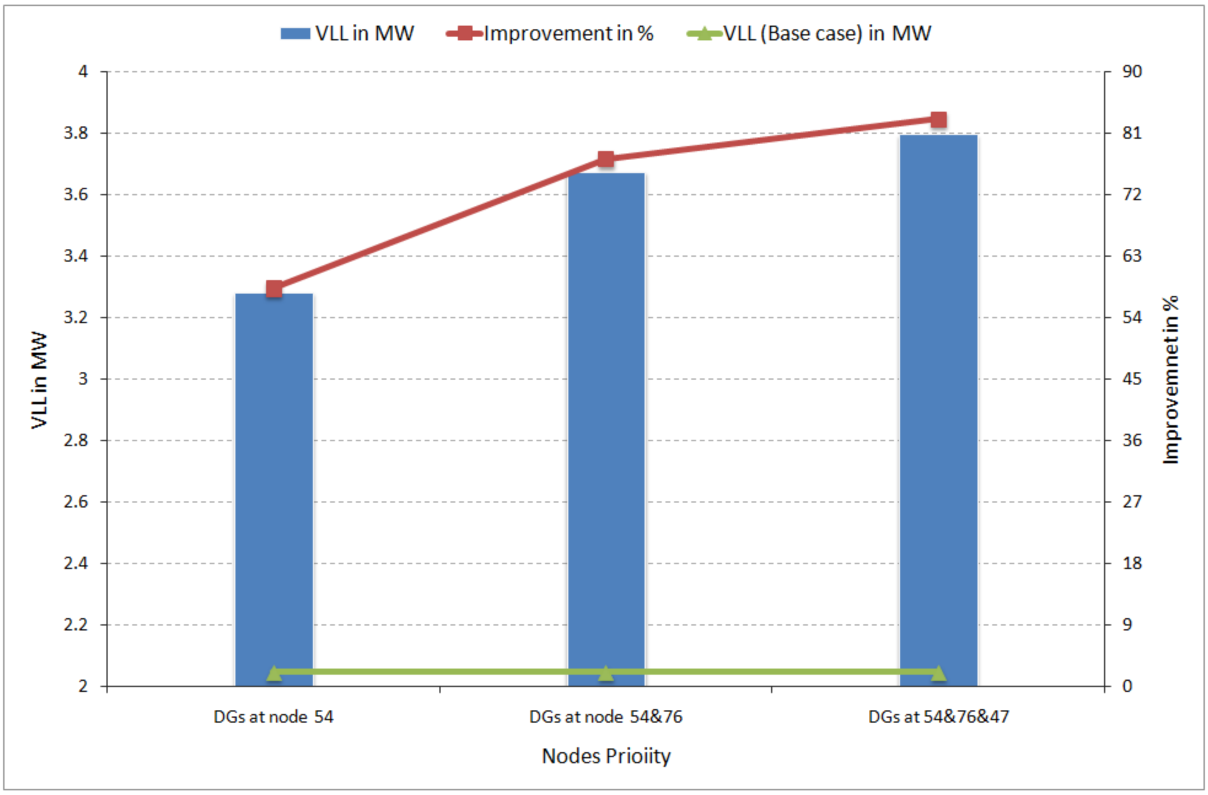

Figure 4 - 4: VLL of the network with integration of DG through different iterations

4.3.2 Second application

The proposed methodology was applied to the test system using different PLs from 20% over 40, 60, 80 to 100%. Moreover, different reactive power injections from DG have been implemented. The dispersion of the DG power between different nodes is applied according to their loads. The resulted recommended locations for different PLs and different reactive power supplied from DG are illustrated in Table 4-2. Figure 4-5 presents the voltage profile of all nodes in the system at the end of different iterations, while 40% PL is implemented. This figure illustrates how the optimal nodes are selected as an example. The rest results will be presented as follows, VLL, VSLL, voltage profile, and system losses.

Table 4 - 2: Recommended locations an DG capacities for different scenarios

PL	20%		40%		60%		80%		100%	
	Node	DG Power (kW)	Node	DG Power (kW)	Node	DG Power (kW)	Node	DG Power (kW)	Node	DG Power (kW)
Unity Power Factor	54	360	54	222	54	332	54	500	54	800
	-	-	76	222	76	332	76	500	76	800
	-	-	47	55	47	84	47	125	47	200
	-	-	51	222	51	332	43	315	-	-
	-	-	-	-	-	-	-	-	-	-
0.95 Power Factor	54	360	54	222	54	375	54	500	54	800
	-	-	76	222	76	375	76	500	76	800
	-	-	47	55	47	94	47	125	47	200
	-	-	51	222	43	236	43	315	-	-
	-	-	-	-	-	-	-	-	-	-
0.9 Power Factor	54	360	54	222	54	375	54	500	54	575
	-	-	76	222	76	375	76	500	76	575
	-	-	47	55	47	94	47	125	47	144
	-	-	51	222	43	236	43	315	84	144
	-	-	-	-	-	-	-	-	43	362

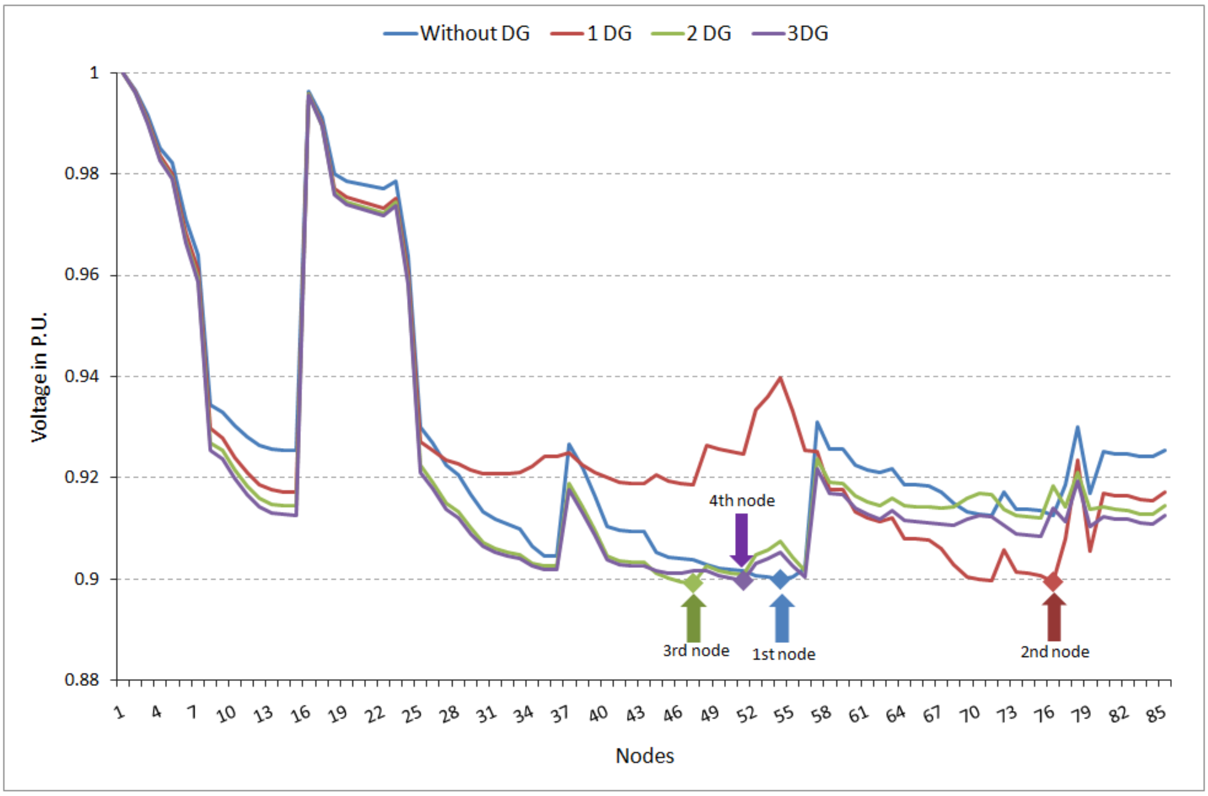

Figure 4 - 5: Voltage profiles with 40% PL of DG units at the end different iterations

- ***Voltage limit loadability***

Fig. 4-6 presents the results of the VLL for 60% PL with different power factors of DG as an example. It can be seen that the VLL is enhanced by 39%, 46%, and 49% when the DG power is integrated at one node for unity, 0.95, 0.9 power factors, respectively. These enhancements are increased to 54%, 64%, and 68% while the DG power is dispersed among different nodes. That means the system with dispersed DG power can be loaded by 311, 373, and 394 kW more than the case of integrating the DG at one node for unity, 0.95, and 0.9 power factors, respectively.

The results of VLL improvement in percentage for all PLs are presented in Fig. 4-7. From this figure it can be concluded that as the PL of the DG increase, dispersing of DG power has a significant impact on enhancing VLL. For example, the difference between the improvement percentages while implementing concentrating and dispersing scenarios are 8%, 12%, and 12% for 40% PL scenario while the differences are 26%, 28%, and 33% for 100% PL scenario. Moreover, it can be demonstrated that with the same PL of DG, dispersing DG power of the same power factor enhance the VLL more than increasing the reactive power injected from the same PL of DG at one node. For example, at 80% PL, dispersing the DG units with unity power factor will improve the VLL with 70% while concentrating the same power with 0.95 power factor will improve it by 56%. The same conclusion can be drawn when comparing dispersed DG units with 0.95 power factor which give an enhancement of 82% while concentrated the same power of 0.9 power factor will result in 60% improvement.

Figure 4-8 presents the enhancement for all PLs in kW. The most interesting conclusion from this figure is dispersing the DG power enhances the VLL more than integrating this power at one node even with lower capacity. Dispersing 40% penetration level gives the same VLL of a 60% concentrated DG power. Dispersing 60% penetration level gives VLL equal to 100% penetration level. Dispersing 80% penetration level gives VLL more than concentrating 100% penetration level by 319 kW. This means that more loads can be supplied with lower DG power when this power is properly located.

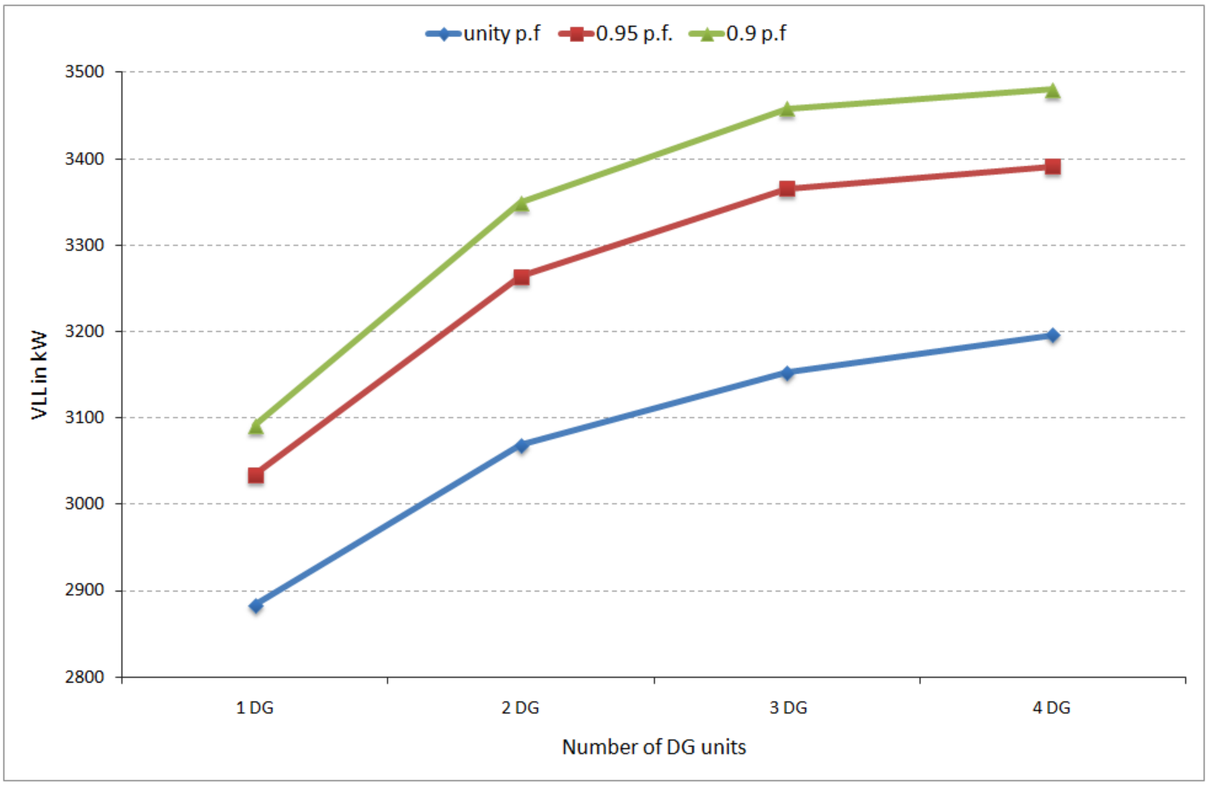

Figure 4 - 6: VLL for different number of DG units with 60% PL

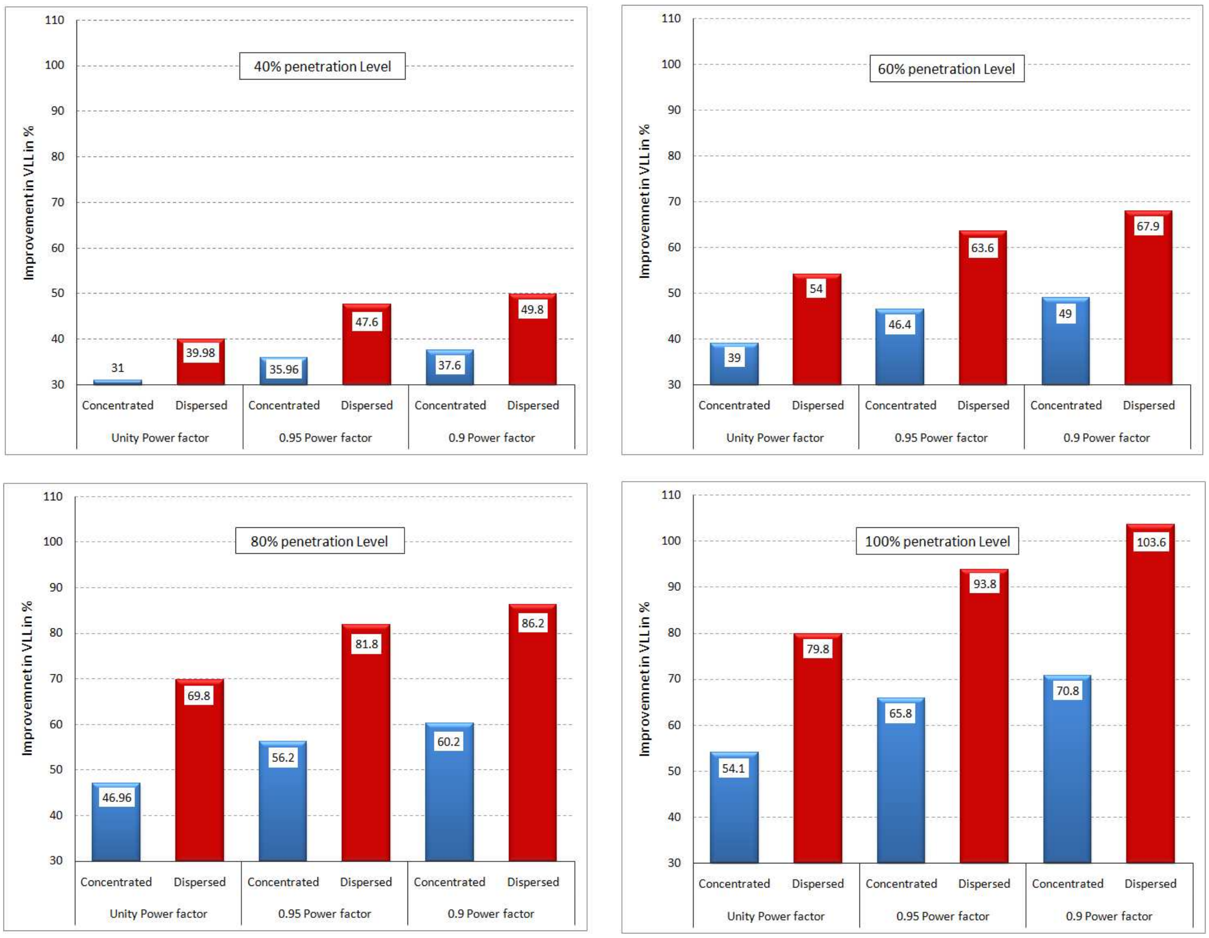

Figure 4 - 7: Improvement in VLL in percentage for different PLs and different Q injections

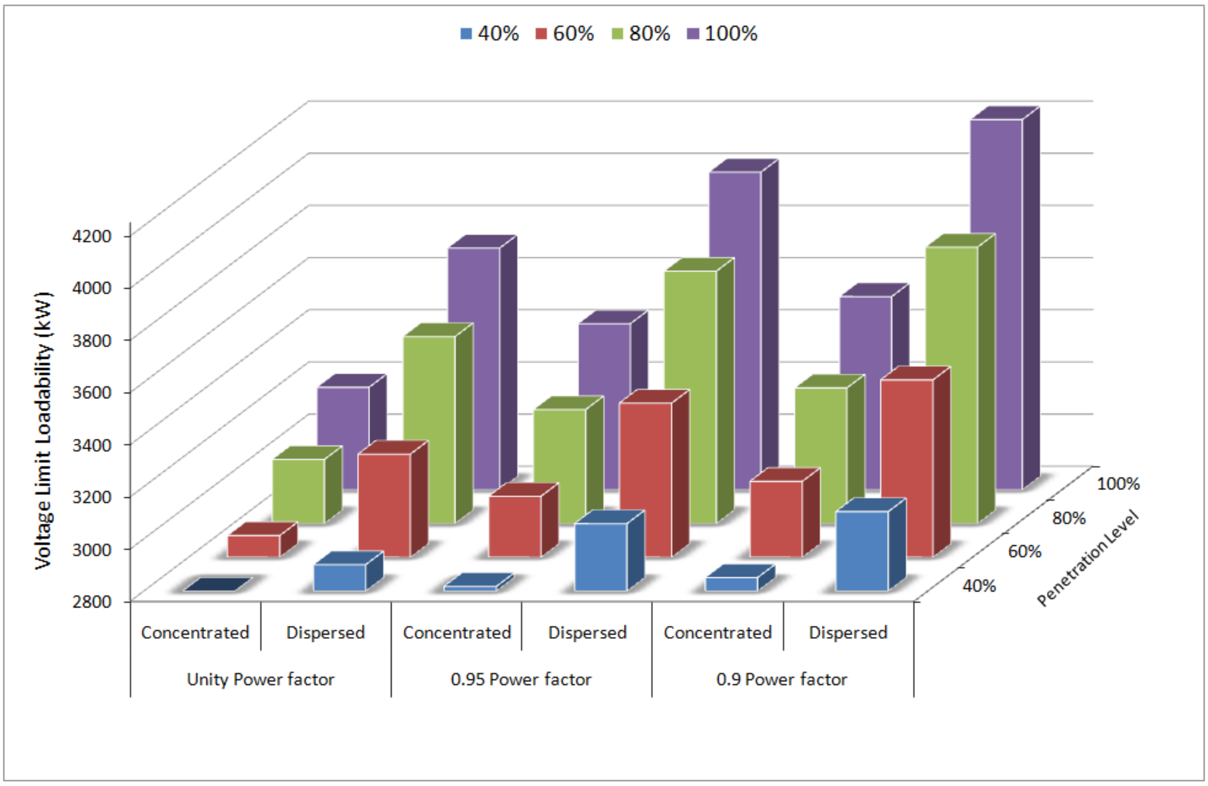

Figure 4 - 8: VLL in kW for different PLs and different Q injections

- ***Voltage stability***

A comparison between the steady state VSLL with integration of 40%, 60% and 80% PLs with different reactive power injections is shown in Fig. 4-9. It can be seen that the VSLL is approximately enhanced by the same level for each PL and different power factors regardless the DG power is dispersed or concentrated. Comparing these results with the results which are achieved in Chapter 3 using the voltage stability index, it can be inferred that in this case the weak points are selected and the DG power is dispersed according to the load at each node. Where at that case in chapter 3 the power is first concentrated at one node and a lower value of power is dispersed into two points. This means that the first point wasn't a weak one, while the other two points were weak points. Moreover, it can be said that the voltage stability indices present the voltage stability from the voltage profile point of view and the situation will be different approaching the maximum loading point.

- ***Voltage profiles***

Figures 4-10 and 4-11 show the voltage profile of the system with integration of 80% PL with unity and with 0.9 power factors at one, two, three, and four nodes, respectively. It can be demonstrated that dispersing the DG power makes the voltage more uniform, while integrating all DG power at one node increases the voltage at a certain area of the network and leave the voltage at other areas low. It can be inferred also that the voltage profile is not a good indicator for VLL margin; therefore VLL has to be evaluated using different methods e.g. CPF. For example if the voltage profiles of the second, third, and fourth iteration in Fig. 4-10 or 4-11 are compared a slight difference is observed, while a difference is exist in the improvement percentage of the VLL.

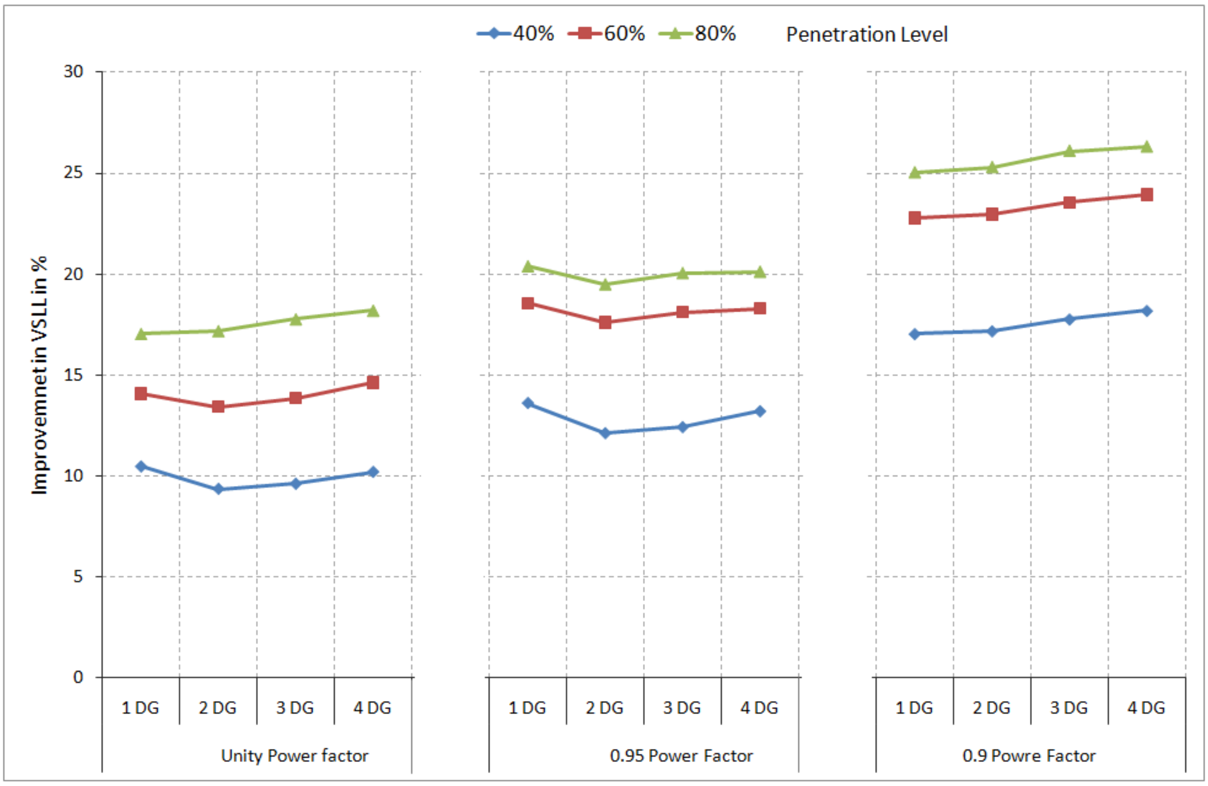

Figure 4 - 9: Improvement of VSLL in % for different PLs and different number of DG units

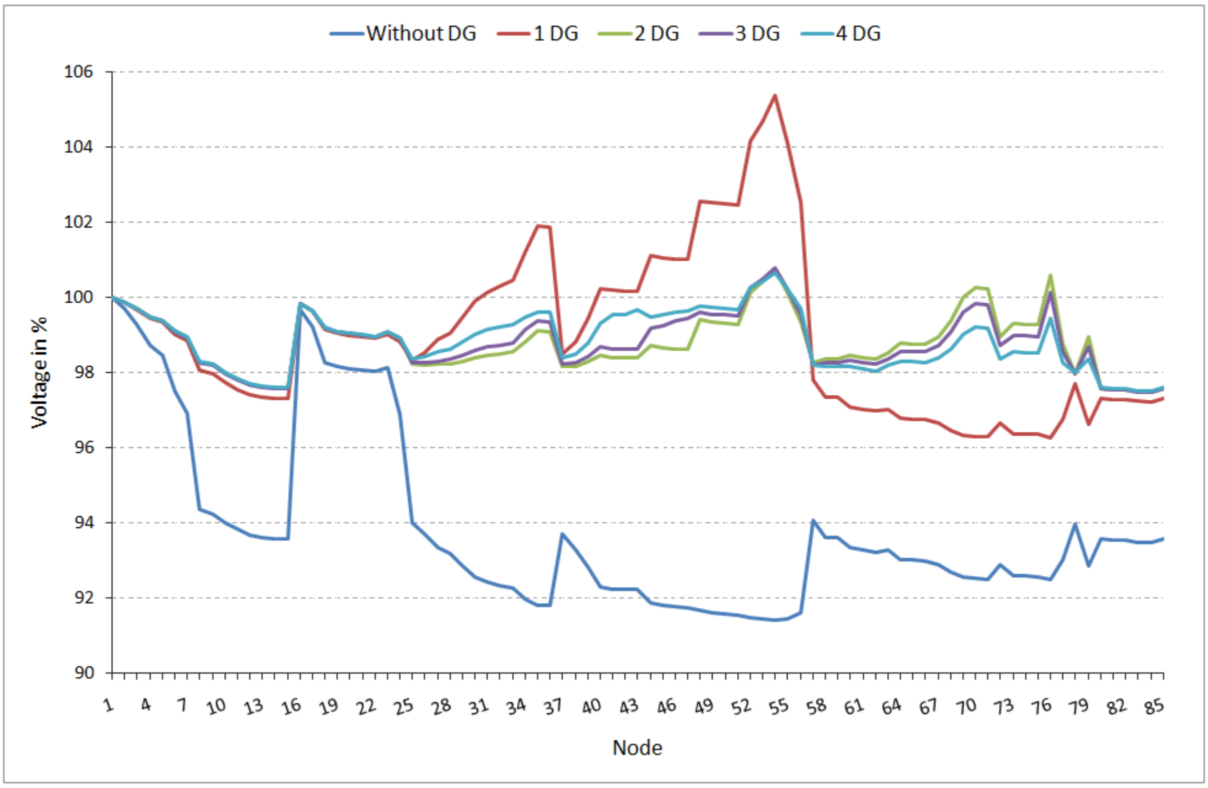

Figure 4 - 10: Voltage profiles with 80% (0.9 power factor) PL for different DG units number

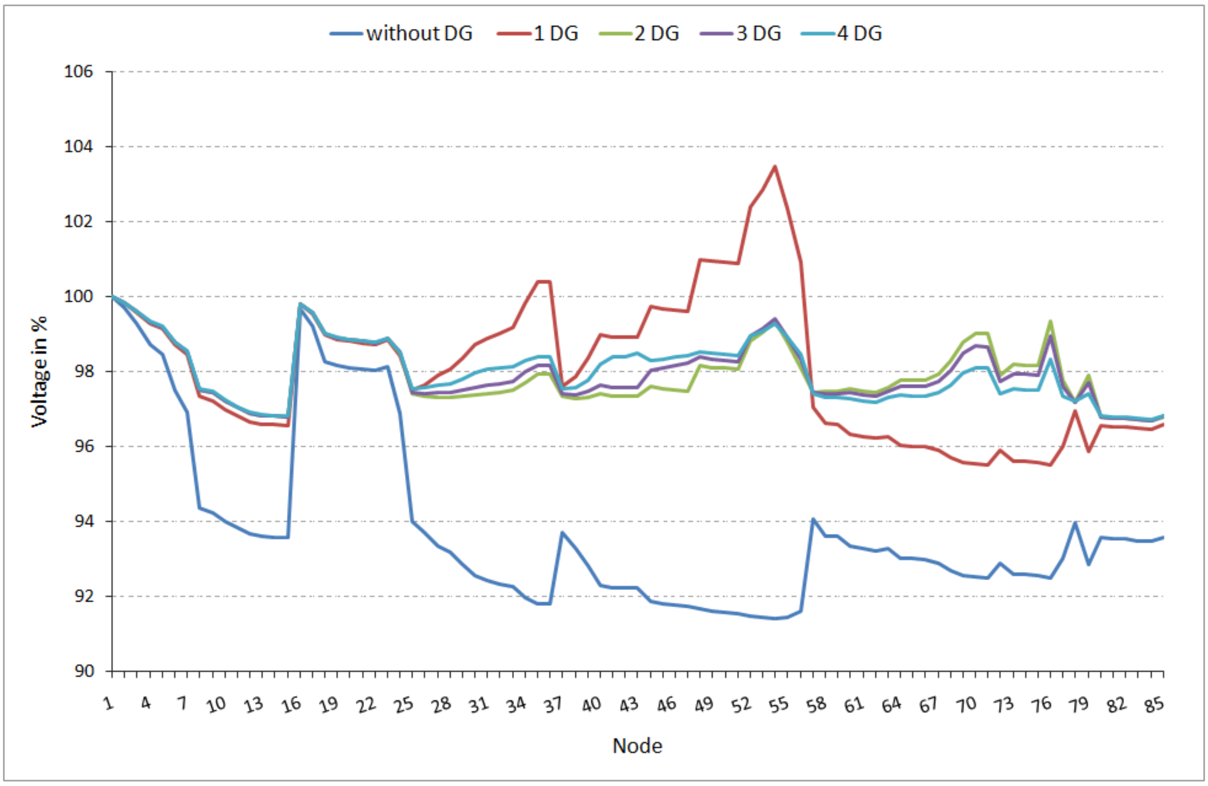

Figure 4 - 11: Voltage profiles with 80% (unity power factor) PL for different DG units number

- ***Losses***

The real and reactive power losses of the network without DG have been found to be 142.5 kW and 90 kvar respectively. Figures 4-12 and 4-13 show the variation in the real and reactive losses of the system with integration of DG (with different reactive power injections and different PLs) as concentrated and dispersed power. It can be seen in Fig. 4-12 that the PLs of 40 and 60% dispersing the DG power will reduce the losses more than concentrating it, however all variations are negative. In the other hand at 80% penetration level with unity power factor, dispersing the DG power will move the change from an increase of 10% to a decrease of 40%, while with reactive power injections the two scenarios will decrease the losses but with dispersing more decreasing can be achieved. For the case of 100% penetration level the losses is moved from an increase of 45% to a decrease of 21% for unity power factor, while for 0.9 power factor the losses is moved from an increase of 15% to a decrease of 71%. These results in addition to the results detailed in Chapter 3 confirmed that controlling the reactive power has a significant impact on the losses of the system. For reactive power losses for approximately all of the cases dispersing the DG power move the losses to a high decrease especially at high penetration levels.

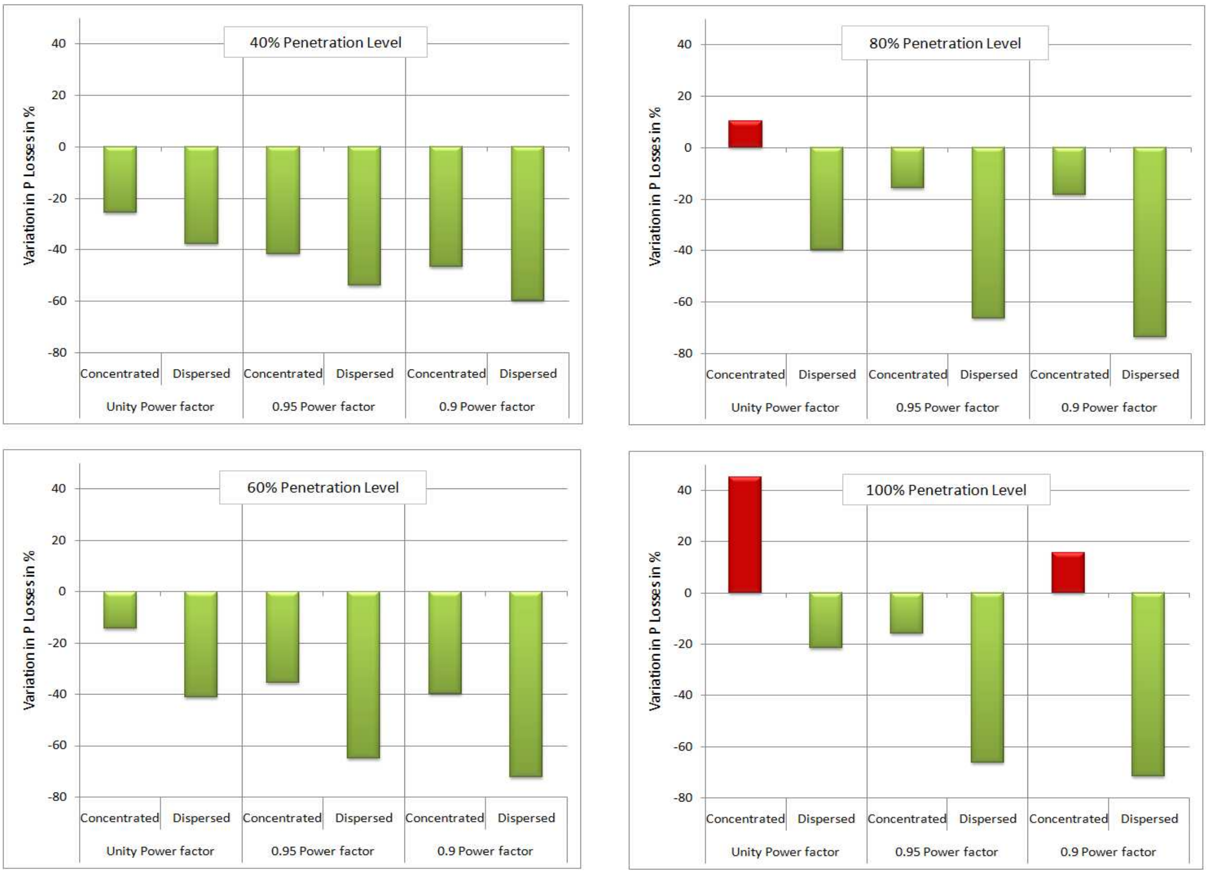

Figure 4 - 12: Variation of real power loss with integration of DG units

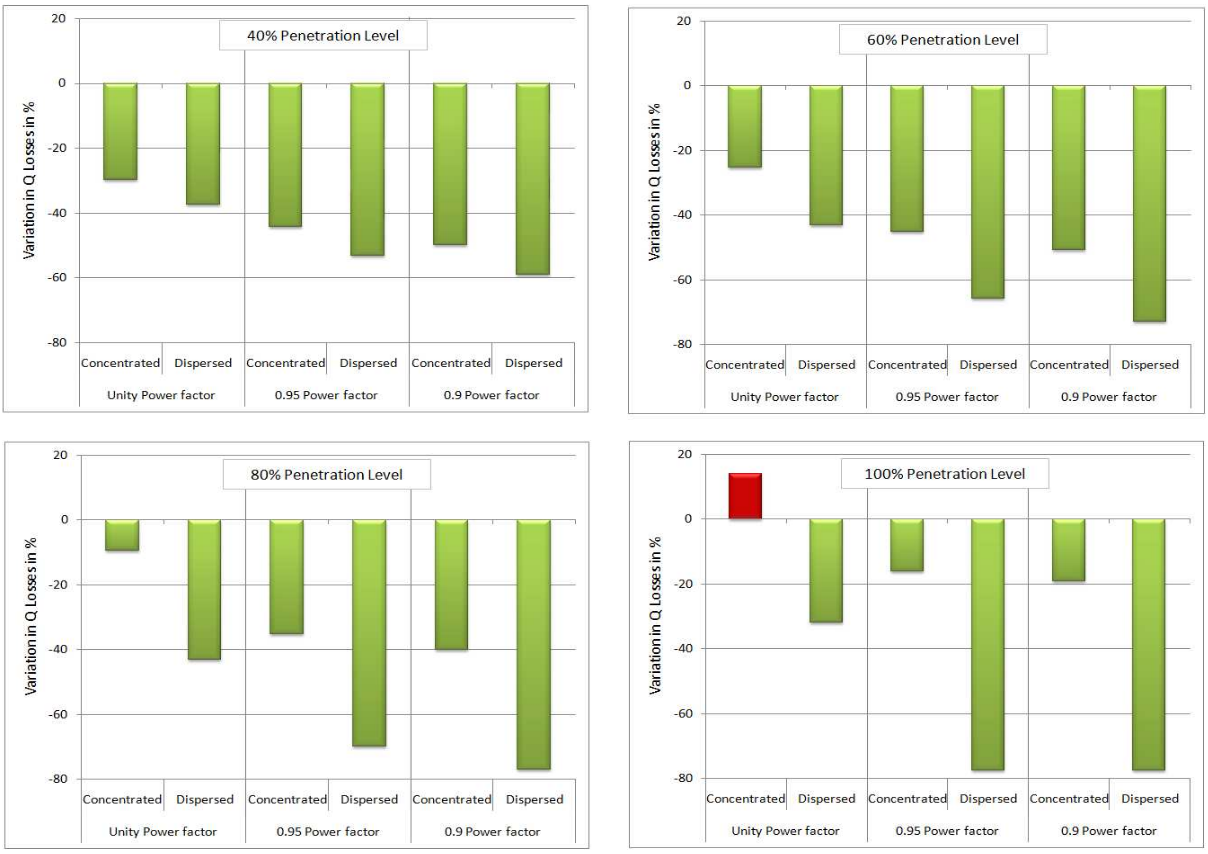

Figure 4 - 13: Variation of reactive power loss with integration of DG units

4.4 Summary

In this chapter a new methodology for placing multi-DG units at distribution networks for enhancing the VLL was introduced. The proposed algorithm has the ability to identify some recommended nodes for connecting DG as a solution to the increasing in the load demand. The proposed method was implemented on a distribution network and the results yield efficiency in increasing the amount of the load which can be supplied from the system while the voltages remain within the limits. As an answer to the question which was highlighted at the introduction of this chapter, it can be said that DG can provide a part of the solution of the problem of the dramatically load increase all over the world, if they are properly located.

For implementing the new proposed algorithm for planning of new integration of DG units, more technical issues have to be taken into consideration. The thermal limits of the line may be included in the algorithm. Moreover, the higher voltage limits in case of light load has to be taken into consideration. In this case, it will be more helpful if the algorithm is implemented based on load profiles of the feeders.

The conclusions which can be drawn from implementing the new algorithm are:

- Dispersing the same amount of the DG power at different nodes of the network enhances the VLL of the network more than concentrating this power at one node.
- More loads can be supplied with lower dispersed power of the DG when it compared with higher concentrated DG power.
- Dispersing the same power of the DG does not approximately affect the VSLL of the network when it compared with integration of the same DG power at the weakest node.
- The voltage profiles through the nodes are more uniform in the case of the dispersed DG power than those of the concentrated DG power.
- Integrating the DGs at the recommended nodes helps to get more decreasing of the active and reactive power losses.

CHAPTER 5: TIME SERIES BASED IMPLICATIONS OF DECENTRALIZED WIND POWER GENERTAION ON REAL MV DISTRIBUTION GRIDS

Wind energy will play an important role in all future power supply concepts. Already today in some countries the contributions from fluctuating wind power have reached considerable high levels causing contingencies in the grid. This fluctuating power will significantly influence the operation of transmission and distribution systems as well as the operation of the conventional power plants.

An early feed-in law for wind electricity was introduced in Germany in 1991. The Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz/EEG) came into force in 2000. Since then, under EEG regulations top priority for grid connection, grid access in either distribution and transmission grid, and power dispatch is given for the electricity produced from renewable energy sources. Grid operators are obliged to feed in electricity produced from renewable energy and buy it at a minimum price within their supply area. These regulations also introduced a German-wide scheme to equalize these costs incurred by grid operators, as the amount of renewable energy being fed into the system differs in the various regions. The law was amended in 2008. Furthermore, the new German EEG requires grid operators not only to extend the existing grid, but also to optimize and enhance it [BWE Website,2010].

By the end of 2009, 21,164 wind turbines with a total capacity of 25,777 MW were installed in Germany altogether. 38 TWh of wind electricity was generated in 2009. These are 7 % of Germany's net electricity consumption. In 2009, German manufacturers and suppliers contributed to nearly 30% of the total worldwide turnover of 22.1 billion Euros. Together with installation, operation and maintenance services, the wind industry achieved a turnover of more than 8 billion Euros. The sector employs close to 100,000 people [BWE Website,2010]. Figure 5-1 shows the installed MW wind power by the end of 2009 in different German federal states. The share of the wind energy in the net energy consumption in each federal state is also illustrated. It can be seen that the maximum wind energy share reaches 47% of the net energy consumption in a certain state. It can be also noticed that the maximum installed wind capacity is found in Lower Saxony (Niedersachsen).

In the future the share of the wind energy in the total energy consumption will be increased as the objective of the German government is to raise the amount of total wind generation from 25.8 GW in 2009 to 47 GW in the year 2020, which will be equal to 60 % of the total load of Germany [BWE Website,2010;Völler et al.,2009].

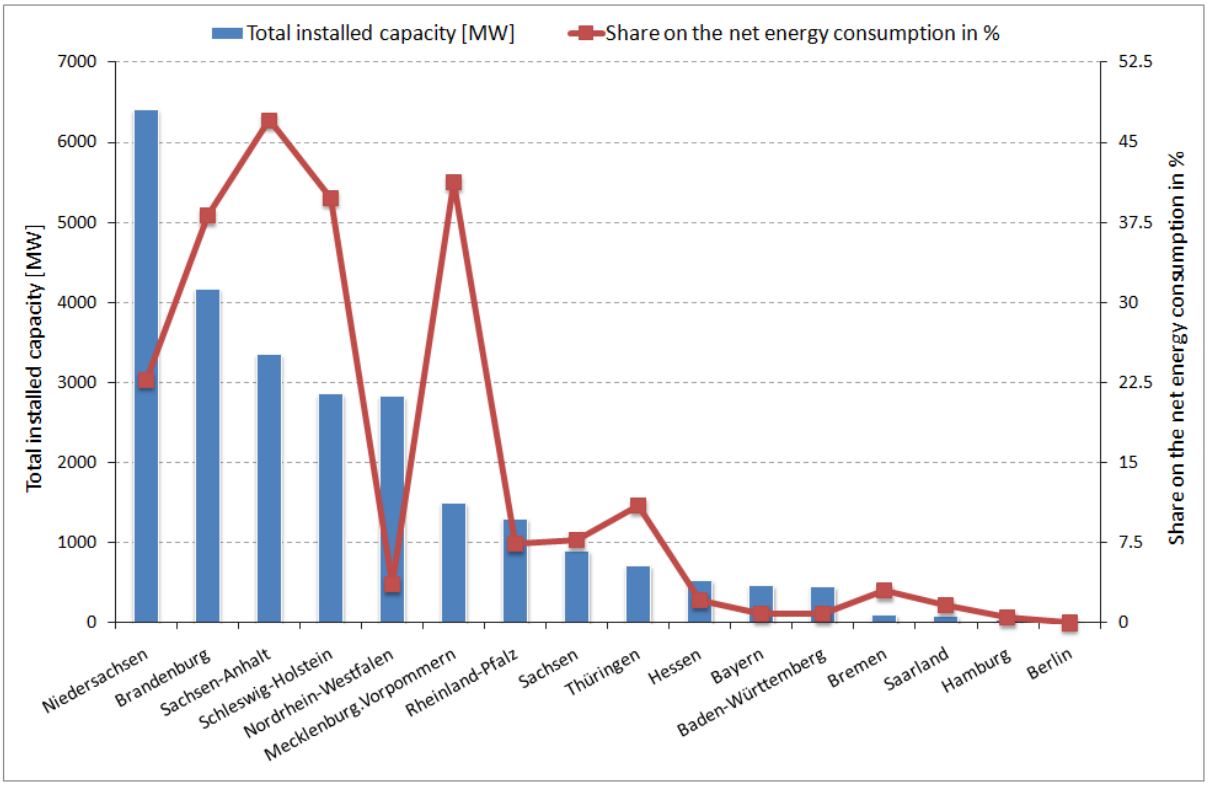

Figure 5 - 1: Total installed wind capacity in different German federal states

The use of Decentralized Wind Power Generation (DWPG), in distribution networks can offer several benefits. However, the interaction between DWPG and the distribution network involves several phenomena that require careful investigation. The integration of the DWPG may have potential impacts on the voltage profiles and voltage ranges that need to be addressed.

Investigations on the implications of DWPG on the voltage ranges, voltage profiles, line loading, and energy losses of a real MV distribution grid are presented in this chapter. The availability to interconnect a new wind mill into a grid that already contains three wind mills has been tested. In the simulation, we used a one year measured wind data and simulated load profiles of the households which are connected to the LV side of each MV substation.

5.1 Study System Characteristics

Figure 5-2 presents the one line diagram of the MV grid under study in the NEPLAN space. The network consists of four areas; the geographic illustration of these areas is also presented in Fig. 5-2. This network is operating at 20 kV. The energy is supplied to the network through a 40 MVA, 110/20 kV transformer located at the main station and also from three wind generators of 0.5, 0.6, and 2 MW connected at MV-A3-2, MV-A3-1, and MV-A3-3, respectively in area No.3 (A3). The load is connected at each MV substation through transformers of 20/0.4 kV with different ratings. Table 5-1 presents the numbers and ratings of different transformers which exist in the network for the loads and wind generators as well. Table 5-2 shows the number of households which are connected to the LV side at each MV substation. Using this table, substations which are connected in the same area can be determined. Each MV substation name comprises the number of the area where this substation is connected and the node number. For example station MV-A1-1 denotes the MV substation in A1 and this substation is connected to node No. 1 in that area. It can be noticed that A1 is the largest area and it contains the largest number of substations and households, while A3 is the smallest area with a small number of households. The real network data are comprised of the number of households at each substation, transformer data, line data and wind generators measured data through one year. The GIS system provided by the utility company was used to define some line data of the system.

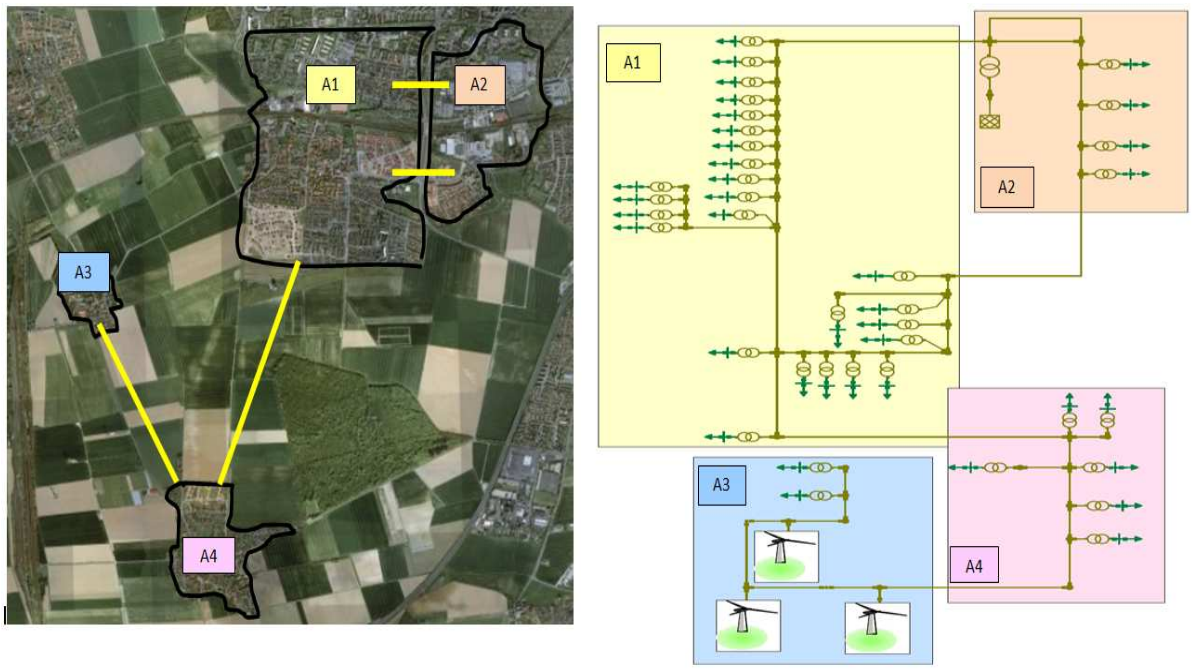

Figure 5 - 2: Geographic illustration of different areas of the system and the network in NEPLAN space

Table 5 - 1: Number of different transformers in the network

Transformer rating	110/20 kV	20/0.4 kV
40 MVA	1	-
2500 kVA	-	1
800 kVA	-	1
630 kVA	-	9
400 kVA	-	14
250 kVA	-	18

Table 5 - 2: Number of households at each MV substation

SS	No. of households	SS	No. of households
MV-A1-1	8	MV-A1-21	52
MV-A1-2	174	MV-A1-22	142
MV-A1-3	124	MV-A1-23	10
MV-A1-4	3	MV-A1-24	105
MV-A1-5	7	MV-A1-25	78
MV-A1-6	1	MV-A1-26	112
MV-A1-7	129	MV-A1-27	121
MV-A1-8	47	MV-A2-4	156
MV-A1-9	29	MV-A2-3	78
MV-A1-10	44	MV-A2-2	120
MV-A1-11	122	MV-A2-1	1
MV-A1-12	73	MV-A3-6	47
MV-A1-13	78	MV-A3-7	91
MV-A1-14	124	MV-A4-1	41
MV-A1-15	125	MV-A4-2	35
MV-A1-16	65	MV-A4-3	72
MV-A1-17	8	MV-A4-4	77
MV-A1-18	105	MV-A4-5	20
MV-A1-19	25	MV-A4-6	49
MV-A1-20	105		

5.2 Load and Generation Profiles

5.2.1 Load profiles

The operators of distribution networks need to apply simple methods to estimate the power flow to the end customers for the inquiry of the power demand balance. Hence, for this customer group with less than 100,000 kWh of annual consumption or less than 50 kW of connection, standardized load profiles were provided. For small customers, the installation of a load meter is not economic due to the technical and organizational expenditure, furthermore the substantial costs [WKO Website,2009]. In the first phase of the liberalized market, the standard load profiles defined by the VDEW (Verband der Elektrizitätswirtschaft, which became BDEW Bundesverband der Energie- und Wasserwirtschaft) are applied in Germany since 01.10.2001 according to VDEW publication "Repräsentative VDEW-Lastprofile" (M-28 / 99) [Meier et al.,1999]

- ***VDEW load profiles***

The VDEW load profiles are provided for different load types as follows [Meier et al.,1999]

- H0: Household
- G0: Commercial General
- G1: Commercial weekdays from 8:00 to 18:00 O’clock
- G2: Commercials with strong to prevailing consumption in the evening hours
- G3: Commercial consecutively

- G4: Shop / Barber
- G5: Bakery
- G6: Weekend operation
- L0: Farms
- L1: Farms with dairy / moonlighting-breeding
- L2: Other farms

The VDEW standard load profiles are provided for different seasons (Wi, Su, and SA). The year is divided into three time intervals as seen in Table 5-3. The load profiles are assigned for the following days:
Wi – Workday, Wi – Saturday, Wi – Sunday, Su – Workday, Su – Saturday, Su – Sunday, SA – Workday, SA – Saturday, and SA – Sunday.

All existing public holidays in Germany will receive the Sunday profile except of two days: December 24thand 31st, where they will receive the last Saturday profile, unless it falls on Sunday.

For households, which are the main load of the system under study, the load profiles are standardized on an annual energy consumption of 1000 kWh. Figure 5-3 shows the VDEW load profiles for different day types of a household.

Table 5 - 3: Different time intervals in the year

	Season	Time interval	Number of days
Su	**Summer**	15.05 – 14.09	123
SA	**Spring, Autumn**	21.03 – 14.05 15.09 – 31.10	102
Wi	**Winter**	01.11 – 20.03	140

- ***Dynamic factor***

The investigation of the load curves during the year indicated that there is a difference between the household (H0) consumption and the consumption of the other groups. Unlike most of commercials and farms which have a relatively smooth consumption, the household consumption decreases from the winter time to the summer time and increases back in the winter. A fourth order regression model for the load profile through one year was presented by VDEW to describe the dynamics of the loads for each day in the year (see Fig. 5-4). The dynamic function can be defined by the following equation [Meier et al.,1999]:

$$Y = [-3.92 \times 10^{-10} \times a^4] + [3.2 \times 10^{-7} \times a^3] + [-7.02 \times 10^{-5} \times a^2] + [2.1 \times 10^{-3} \times a] + 1.244 \quad (5.1)$$

Where Y is the dynamic factor for a certain day and a will take the values from 1 to 365 represents the day number in the year.

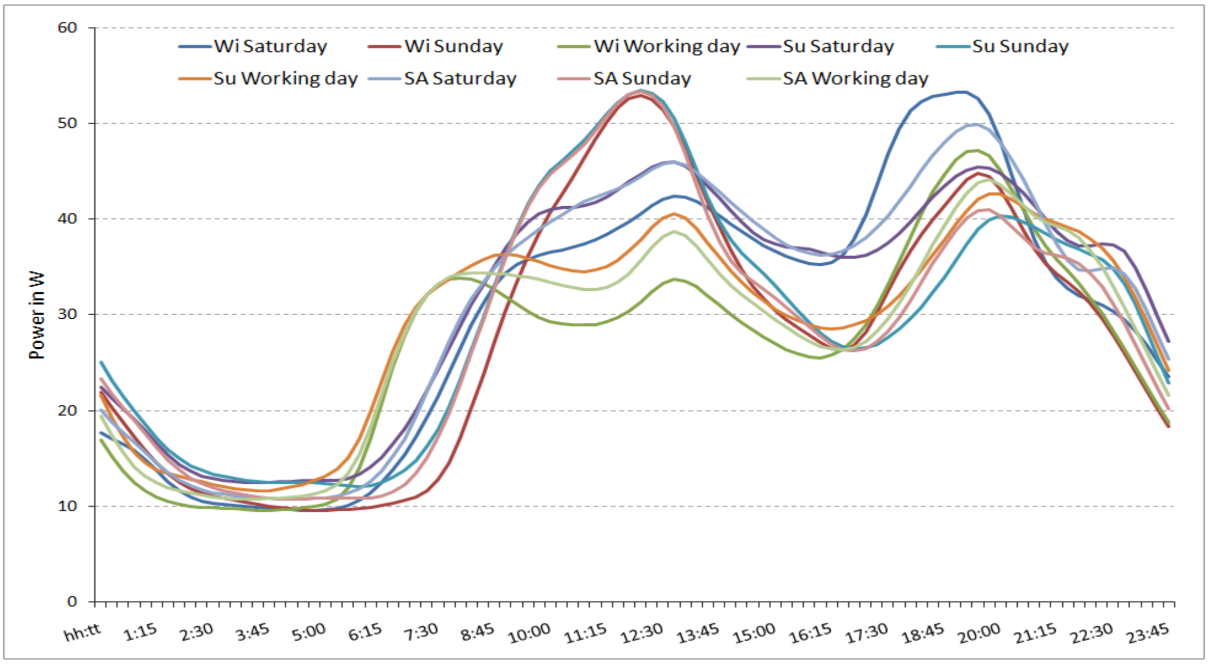

Figure 5 - 3: VDEW load profiles for household standardized on an annual energy consumption of 1 MWh

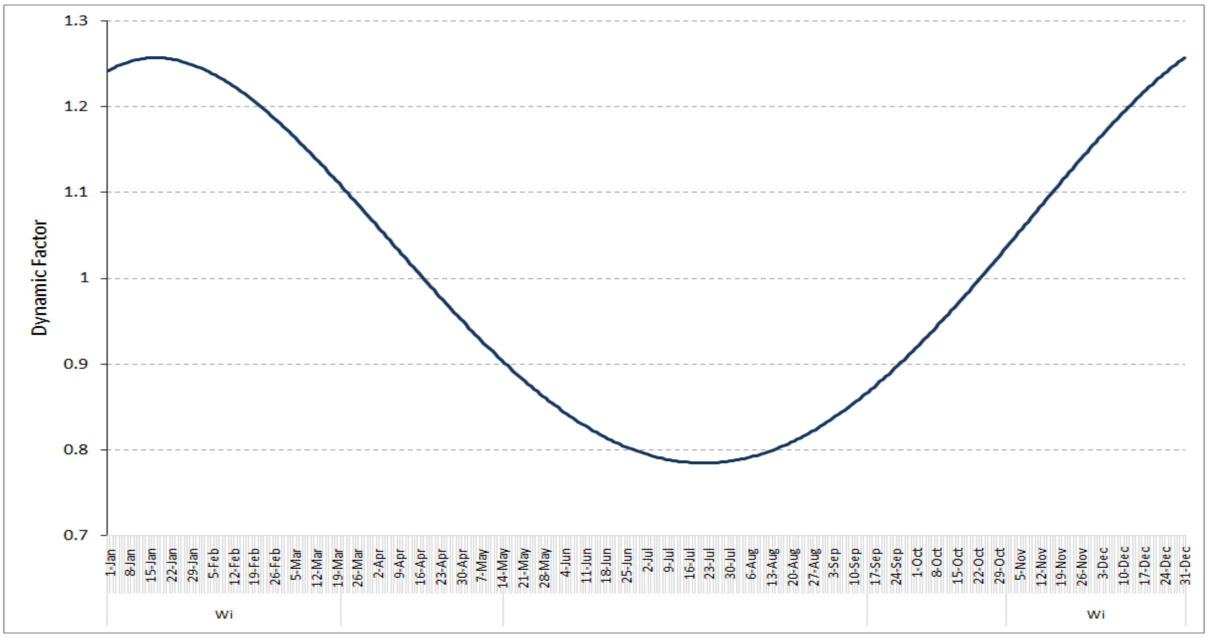

Figure 5 - 4: Dynamic factor

- ***Households consuming groups (CG):***

There are different types of household consumers with different consumption trends which can be defined as follows [Dyussembekova et al.,2008;Kaufmann,1995]:

Basic needs (CG1): The electrical energy is used for lighting and for high consumption appliances such as washing machines. The peak power is 5 kW.

Partial needs (CG2): In addition to the basic needs, electrical energy is used for cooking. The peak power is 8 kW.

Full-electric (CG3): In addition to the partial needs, drinking water and hot water are provided using electric energy. Therefore, the electric energy is increased in the morning and in the evening. The peak power can be up to 30 kW.

All electric (CG4): In addition to the full electric needs a night storage heaters are supplemented.

In the current study, only households as a partial needs consuming group (CG2) are considered with a maximum power of 8 kW.

- ***Simultaneity factor (SF):***

To evaluate the maximum power at each MV substation, two parameters are required to be defined for each consuming household group. The first is the maximum power which can be consumed by each household in a certain group. While the second parameter is the Simultaneity Factor (SF) (Gleichzeitigkeitsfaktor GZF) which can be defined by the following equation [Winter et al.,2001].

$$SF = \left\{ max\left(\sum_{i=1}^{i=n} P_i(t)\right)\right\} \Big/ \left\{\sum_{i=1}^{i=n} P_{N,i}\right\} \tag{5.2}$$

Where $P_i(t)$ is the electric load (kW) of a consumer i at the time t. The max value of the summation for n number of households in the investigated group is taken. $P_{N,i}$is the nominal electric load of consumer i.

For each households consuming group, the maximum power for each household consuming group and the corresponding Simultaneity Grade (g_∞) are given in Table 5-4. Equations (5.3) and (5.4) were presented in [Kaufmann,1995] to evaluate the maximum power which can be consumed simultaneity for a group of households connected to the same MV substation.

Table 5 - 4: Maximum power and simultaneity grade for each household consuming group [Kaufmann,1995]

Consumer group	Maximum power (P) in kW	Simultaneity grad g_∞
CG1	5	0.15 ……... 0.20
CG2	8	0.12 ……... 0.15
CG3	30	0.006 ……. 0.007
CG4	15……18	~0.7

$$g(n) = g_\infty + \frac{1 - g_\infty}{\sqrt[4]{n^3}} \tag{5.3}$$

$$P_m(n) = g(n) \times P \times n \tag{5.4}$$

Where $g(n)$is the simultaneity factor, $g_{\infty}$is the simultaneity grade, n is the number of households, $P_m(n)$ is the maximum power for a group of households connected to the same MV substation, and P is the maximum power for each household (Table 5-4). In the presented work some measured data [e.on Avacon,2007;En BS,2008;VDI,2007], have been used to introduce a new relation between the number of households and the maximum power. The results of this relation are compared with the results of Eqs (5.3) and (5.4), then based on an error analysis the optimal simultaneity grade is introduced.

5.2.2 Generation profiles

Three wind mills of 0.5, 0.6, and 2 MW are already interconnected into the grid under study. They are connected to the grid through 630, 800 and 2500 kVA transformers, respectively. One year measured data of the output power for the three mills is used in this work. The output powers of the existing three wind mills, on January and on July in 15 minutes resolution, are shown in Fig. 5-5.

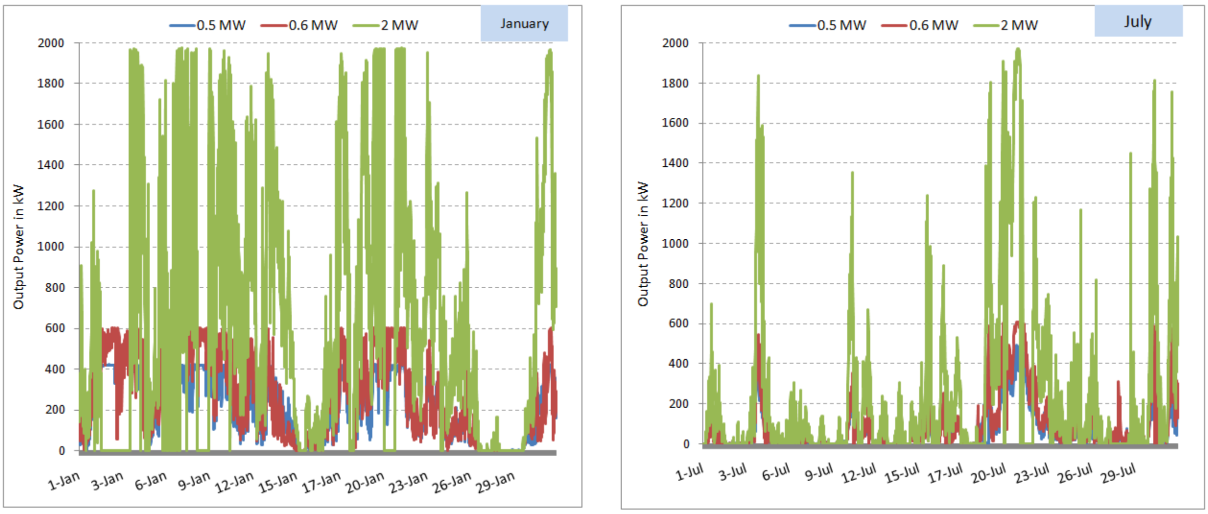

Figure 5 - 5: Measured generated power in January and July of the three existing wind mills

5.3 Results

Through this work, the load flow with load profiles which is implemented in NEPLAN was used in the investigation process. The results will be presented as follows:

- Evaluation of the maximum power at each MV substation.
- The grid voltage ranges, energy losses, and line loading without wind generation.
- The grid voltage ranges, voltage profiles, line loading, supplied power from the main station and energy losses with the existing three wind generation.
- The integration impact of the new wind mill on the voltage ranges and energy losses of the system.
- The integration availability of the new wind mill.

5.3.1 Maximum power at each MV substation

Using the number of households at each MV substation, the maximum power which is consumed simultaneously can be calculated using the following methods:

- A proposed equation which has been generated using the measured data.
- Specific SF for each MV substation using the number of households served by it (using Eqs. (5.3) and (5.4)).

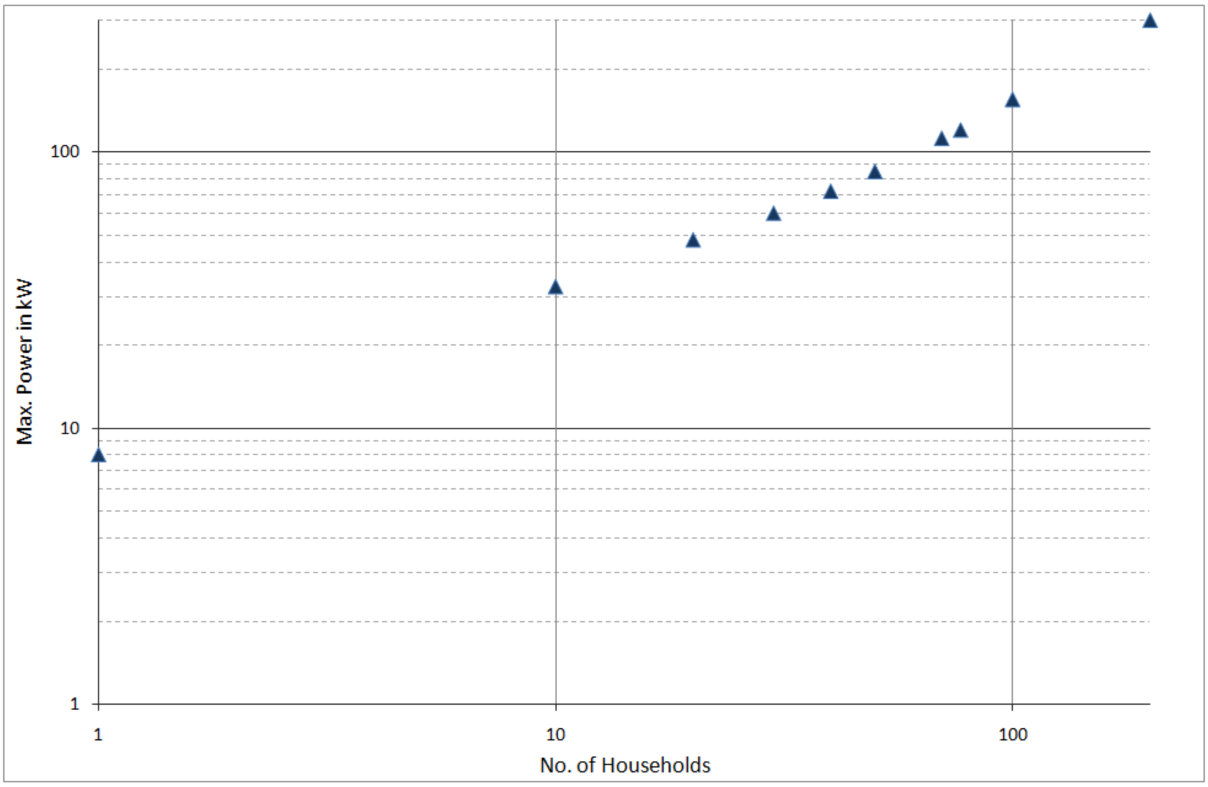

Figure 5 - 6: Measured maximum power [e.on Avacon,2007;En BS,2008;VDI,2007]

Based on the measured data shown in Fig. 5-6, a new relation can be defined as follow:

$$P_m(n) = (1.4214 \times n) + 14.251 \tag{5.5}$$

Where $P_m(n)$ is the maximum power in kW for a group of households, and n is the number of households. This new relation can be used to evaluate the maximum power in kW for a group of households connected to the same MV substation. It was used to calculate the maximum power for different number of households from 10 to 300 and the results of kW/household are given in Fig. 5-7.

Furthermore, the proposed equation is used to optimize the simultaneity grade when the Eqs. (5.3) and (5.4) are used to identify the maximum power. Different simultaneity grade ranges from 0.12 to 0.22 were tested to find the optimum grade closely matches the results of the proposed equation. The results for kW/household for different numbers of households are given also in Fig. 5-7. From this figure it can be inferred that the simultaneity grade of 0.17 is the optimum grade. The absolute percentage error of using 0.17 simultaneity grade can be seen in Fig. 5-8. It can be inferred that using 0.17 simultaneity grades will give results with an error ≤ 2% for a number of households more than 25. The total maximum power of the whole system related to the measured data is 4540 kW, and using a specific SF at each station is 4533 kW. This means that using a specific SF (with g_{∞} = 0.17) gives an error of ~ 0.2%. The maximum powers which are obtained using the new equation are used in the simulation.

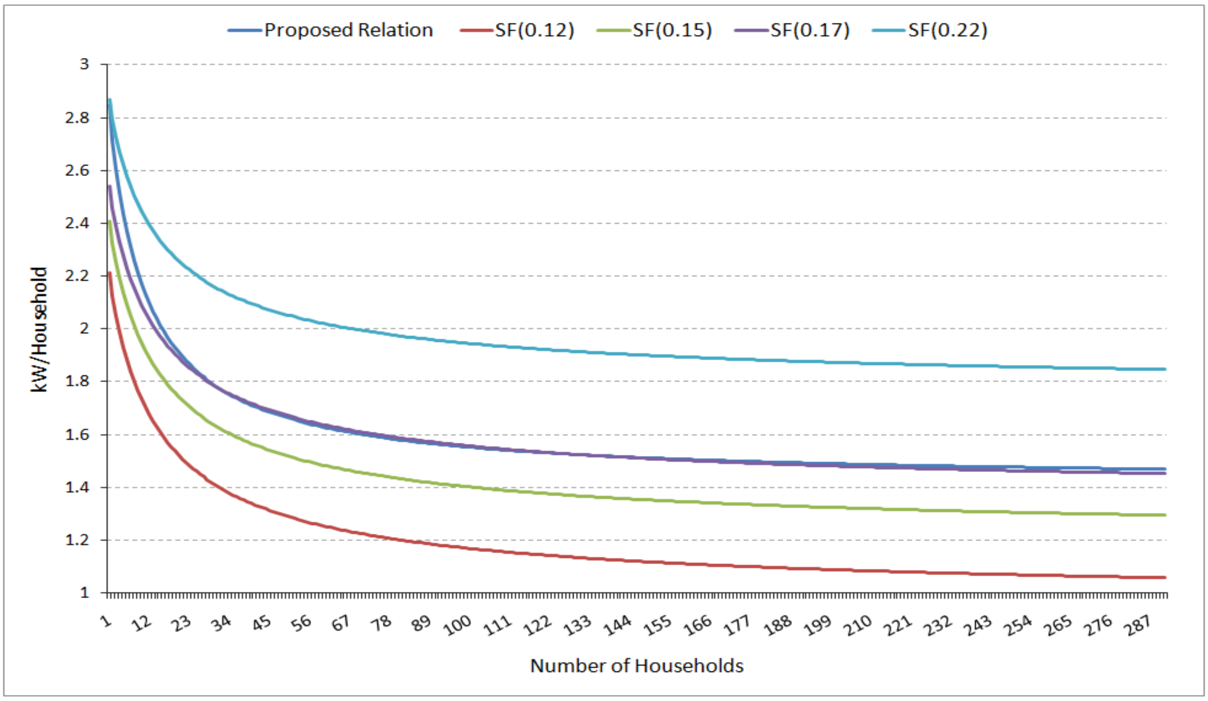

Figure 5 - 7: kW/Household using different methods

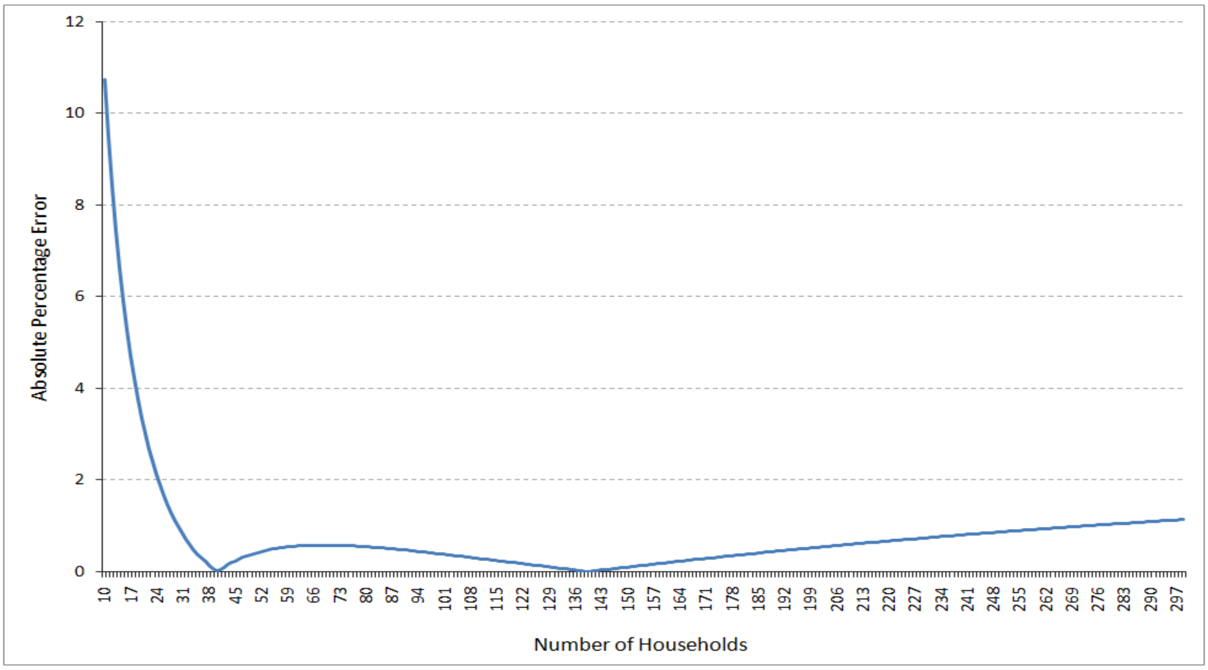

Figure 5 - 8: Absolute percentage error using 0.17 simultaneity grade

5.3.2 Network without wind

- ***Voltage ranges***

The load flow with load profiles is used for the test network through one year. The 110/20 kV transformer is modeled with an on-load tap changer of 1.23% with ±14 tap. This setting is used for all investigated cases. The voltage ranges, the line loading, and the energy losses are investigated without the existence of the wind generation. The voltage ranges through one year of MV nodes are shown in Fig. 5-9. It is clear, that the voltage in MV side varies within ~ 2%.

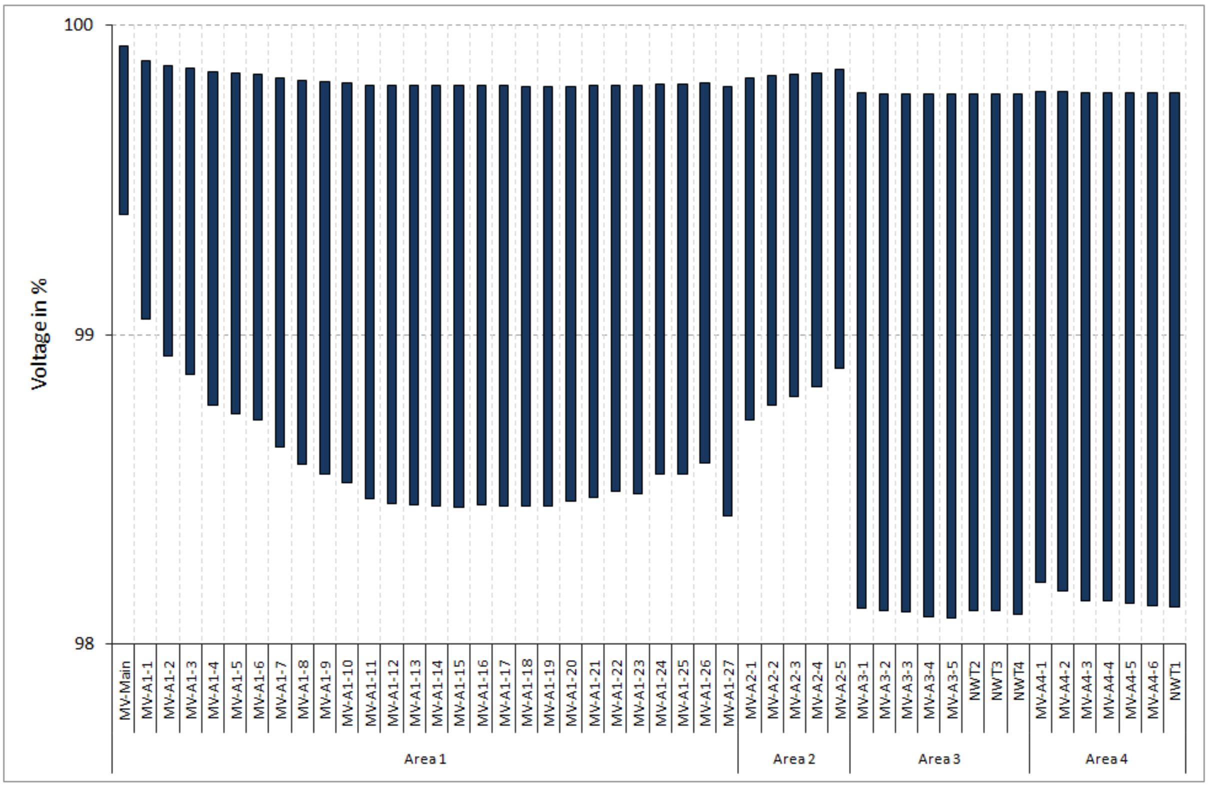

Figure 5 - 9: Voltage ranges through one year for MV nodes

- ***Line loading and energy losses***

The line loading of the network is tested without the existence of any wind generation. It has been found that the lines in A1 are highly loaded because the power is transferred to the rest of the system mainly through them. Also, due to the high number of substation and consequently the high number of households served in this area. A comparison between the line loading without and with the existed wind mills will be presented in the next subsection. The total energy loss of the grid under study in one year is 189 MWh. A comparison between the losses without wind and with wind will be introduced also in the next subsection.

5.3.3 Network with the existence of three wind generators

The network is simulated with three existing wind generators of 0.5, 0.6, and 2 MW. The measured output power for each generator in one year is integrated into NEPLAN and used to investigate the impacts on the voltage ranges, voltage profiles, supplied power from the main station, and energy losses of the system.

- ***Maximum voltage change***

Figure 5-10 shows the voltage profile of substation MV-A4-3 for two days with and without wind. This figure illustrates how the voltage change in percentage is calculated.

The maximum voltage changes for MV nodes when compared to the case of the network without wind are shown in Fig. 5-11. It can be seen that the change in the voltages of A1 and A2 is less than 0.4%. That is because these two areas are connected to the main station through two points and also the wind generators are connected at the end of A3. While the change in percentage of the voltages of the MV nodes in A3 is more than 1.4% due to existence of the three wind generators in this area and also the existence of only two MV substations supplying the power to 138 households. The impact is also high in A4 and the change reaches ~ 1.3% and the reason behind that is the radial connection of A3 and A4 to the network.

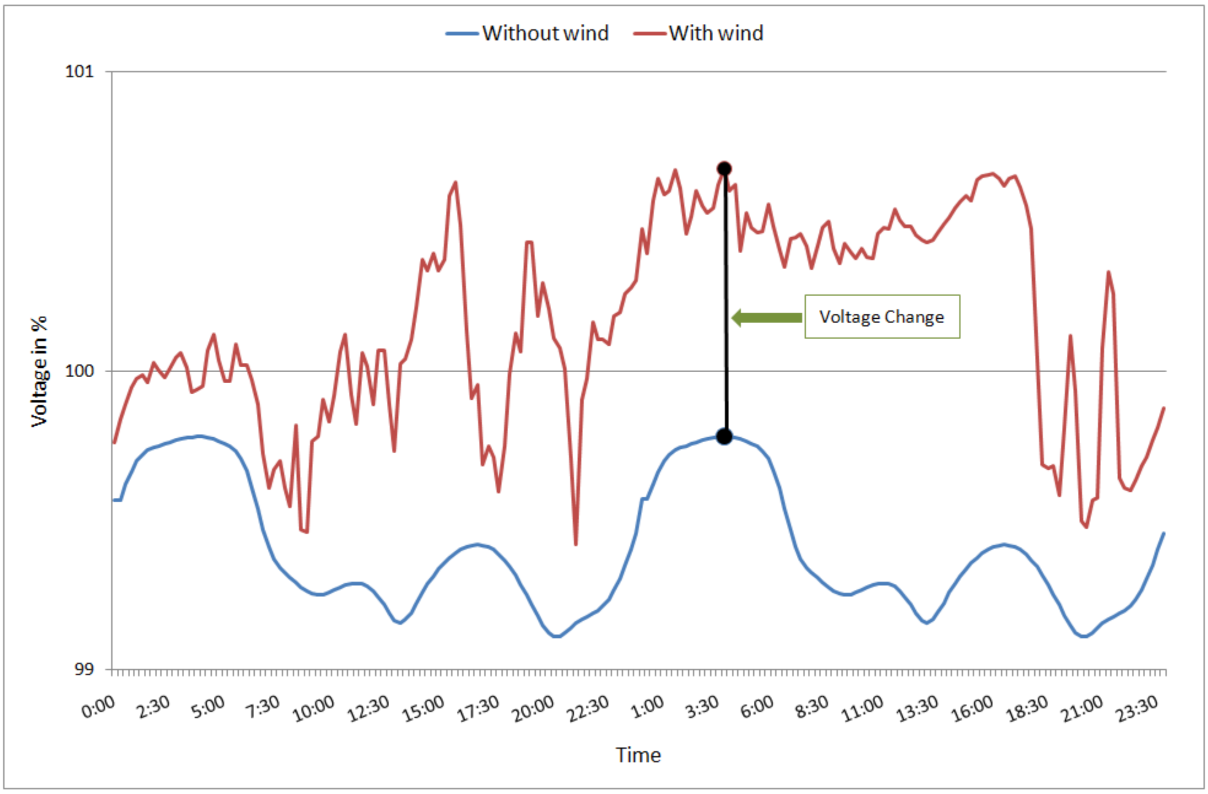

Figure 5 - 10: Voltage profile of one MV node through two days in July illustrating the voltage change evaluation

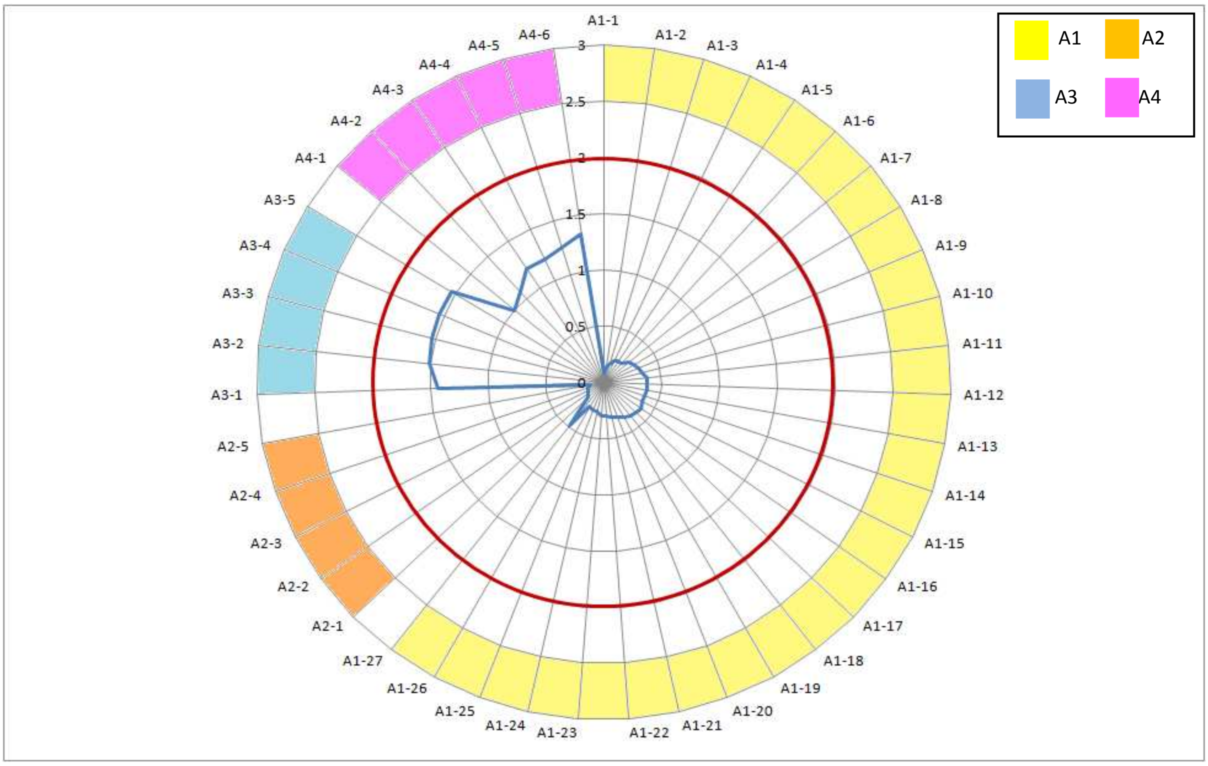

Figure 5 - 11: Maximum voltage change in percentage for each MV node compared to the case without wind

- ***Voltage profiles***

In order to investigate the impact of the DWPG fluctuating power on the voltage profiles in different system areas, two days, one in January and the other in July, are selected to present high load and low load, respectively. The wind output power on 22ndJanuary and the corresponding voltage profiles of MV and LV nodes of each area are presented in Figs. 5-12 and 5-13, respectively. The output wind powers on 30thJuly and the corresponding voltage profiles are presented in Figs. 5-14 and 5-15, respectively. It can be seen that as expected at high load days, the wind fluctuation has a low impact on the voltage profiles compared to the low load days. Moreover, the voltage profiles of the nodes at A3 and A4 are more affected by the fluctuation in the wind power than the other two areas. One of the reasons behind that is the feeder which contains these two areas. This feeder is connected in radial while A1 and A2 are connected to the supply in ring.

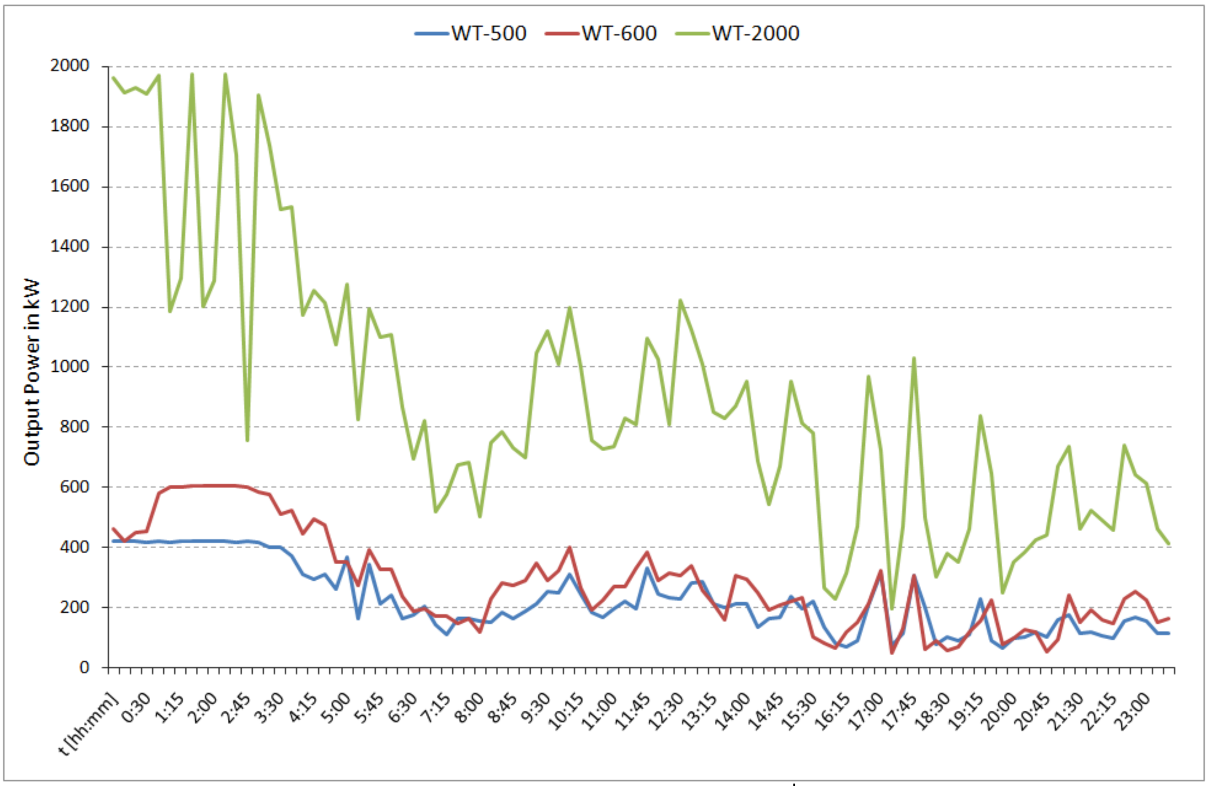

Figure 5 - 12: Output wind power in 22nd January

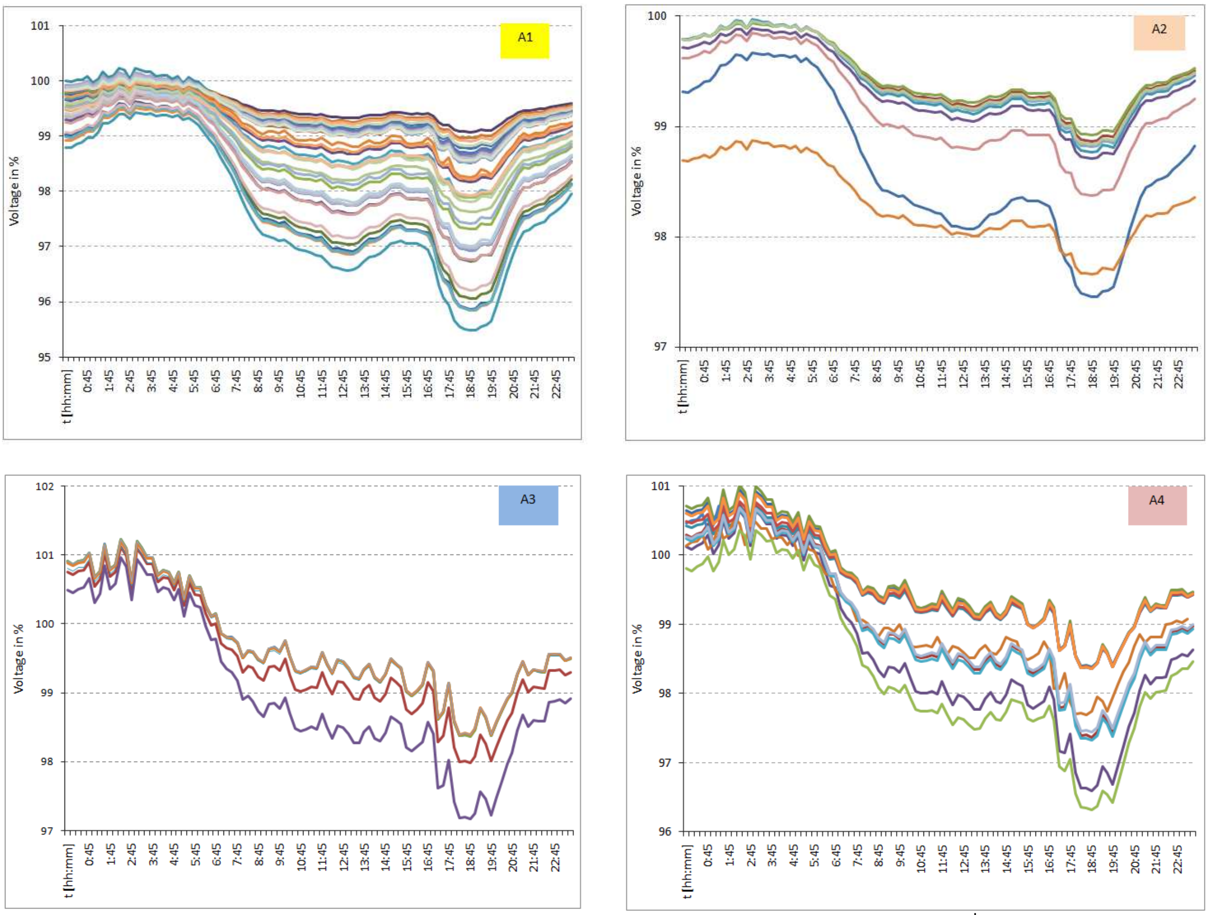

Figure 5 - 13: Voltage profiles for MV and LV nodes at each area on 22nd January

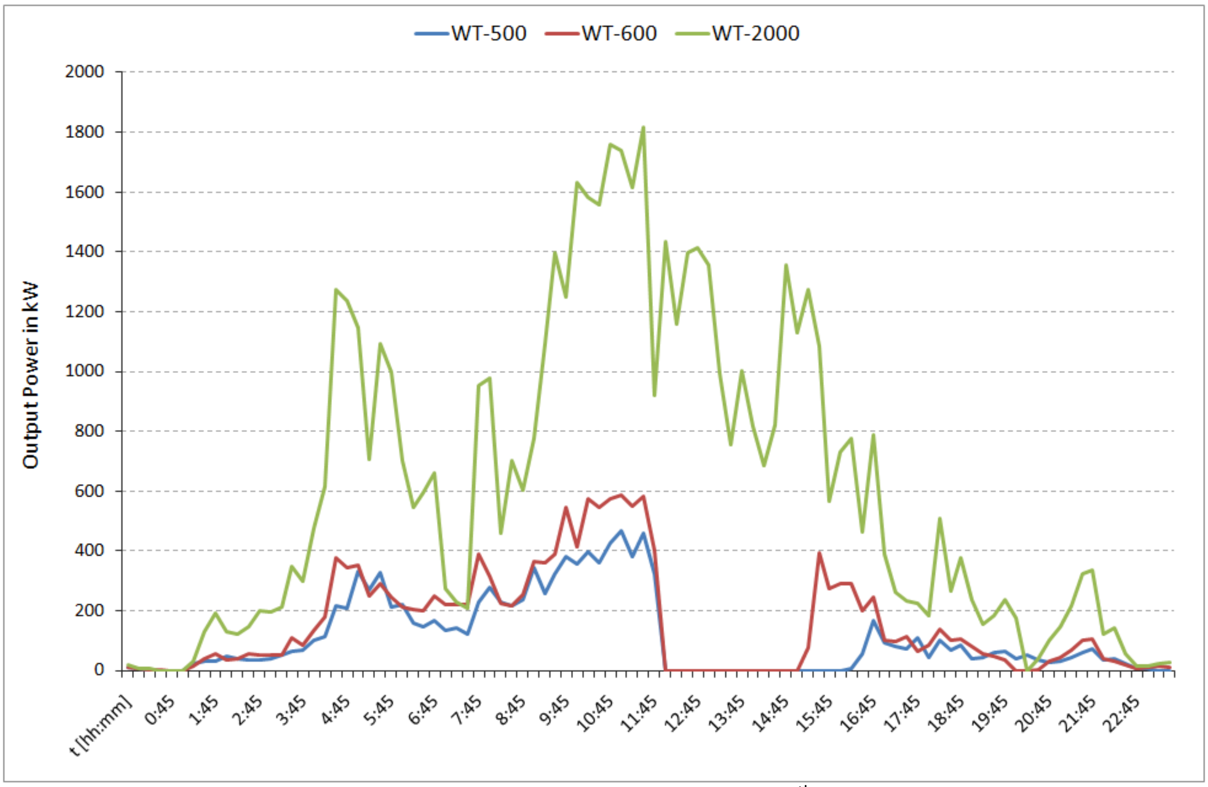

Figure 5 - 14: Output wind power in 30th July

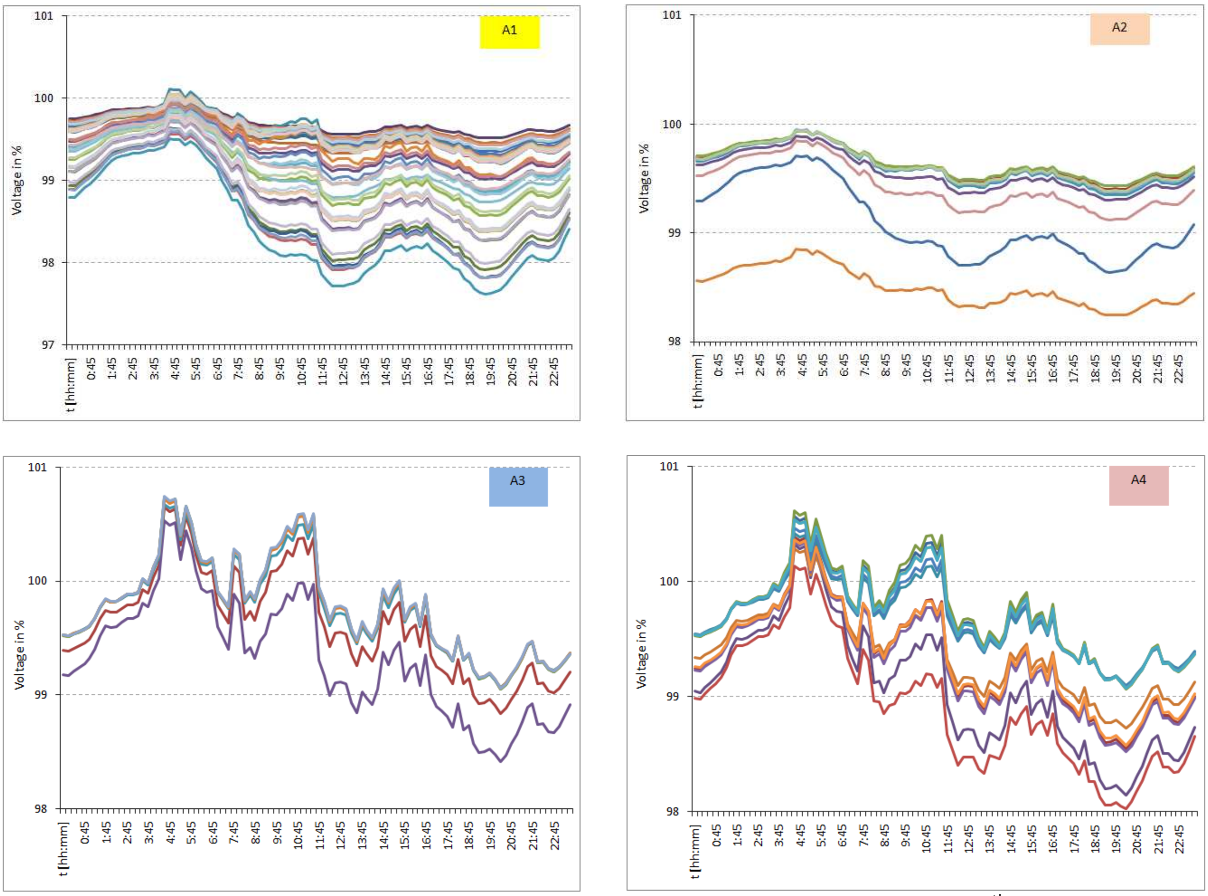

Figure 5 - 15: Voltage profiles for MV and LV nodes for each area on 30th July

- ***Supplied power from the main station***

The supplied power from the main station is investigated through two days, one in January and the other one in July. Figure 5-16(a) shows the supplied power from the main station in the case of without wind compared to the case of existence of the three wind mills on 22nd January. It can be inferred that as the wind power is high in the winter season so that the power from the three wind generators can be more than load power especially during the light load time. Therefore, the rest of the power will flow back to the transmission system. It can be inferred also that the peak power in MW consumed from the main station is decreased by 9.6% with existence of the wind in this day. Moreover, the supplied energy is decreased from 79 MWh to 51 MWh and this means that it is decreased in this day by ~35%. The corresponding losses in the same day are shown for the two cases in Fig. 5-16(b). It can be seen in this figure that in the time when the power flow back to the transmission system the losses are highly increased and it follows the wind profile at that time.

The supplied power in 30th July is shown in Fig. 5-17(a). It can be seen also, that in summer a power flow back to the transmission system can be occurred especially in the light load cases but for a short time compared to the winter season. In this day the peak power is decreased by 5.9% and the supplied energy is decreased from 53 MWh to 33 MWh (-37.5%). The corresponding losses are shown in Fig. 5-17(b). The losses as seen in this figure are increased in the time of high wind power. The increasing rate of the losses depends on the consumed power.

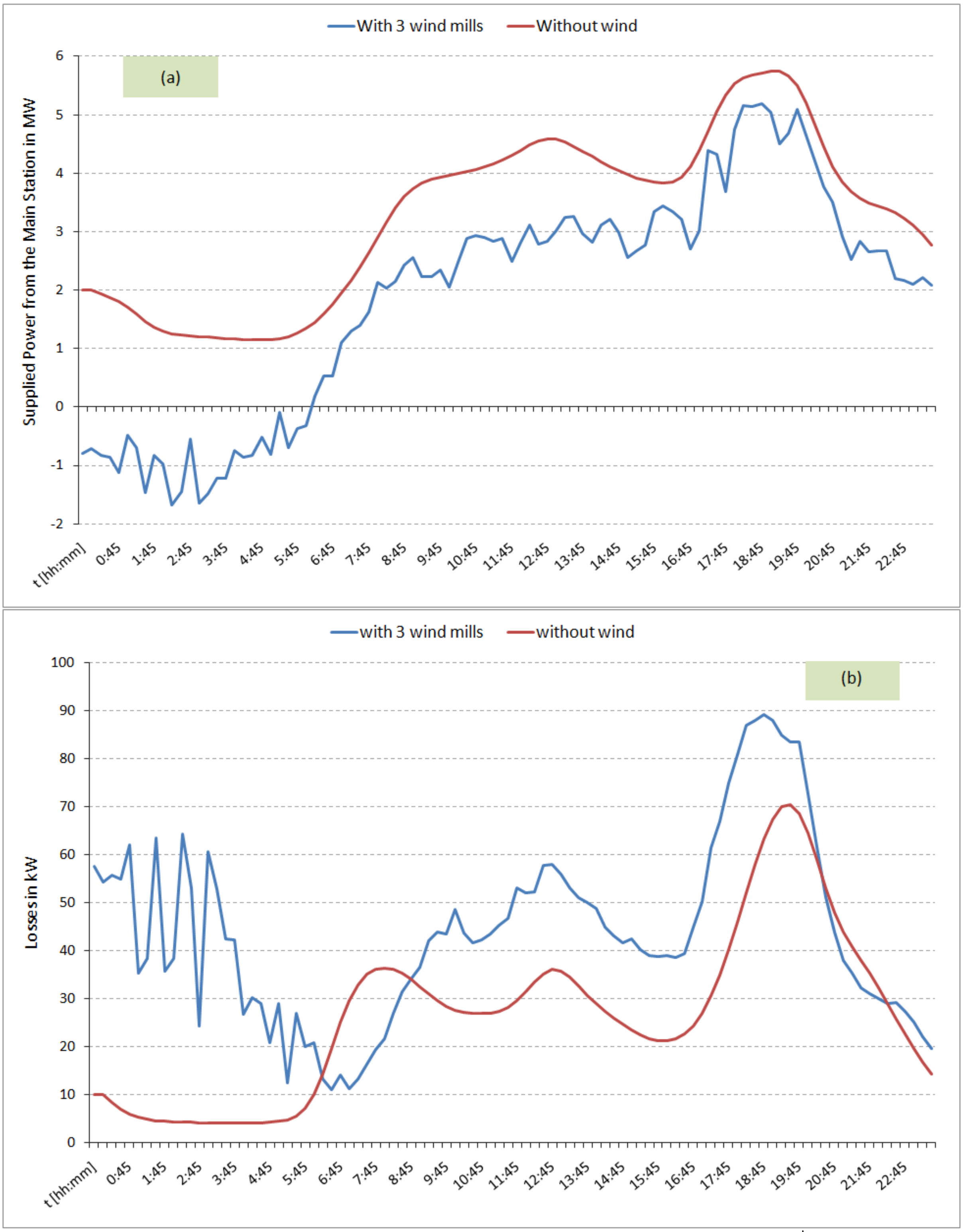

Figure 5 - 16: Supplied power from the main station (a) and losses (b) on 22nd January

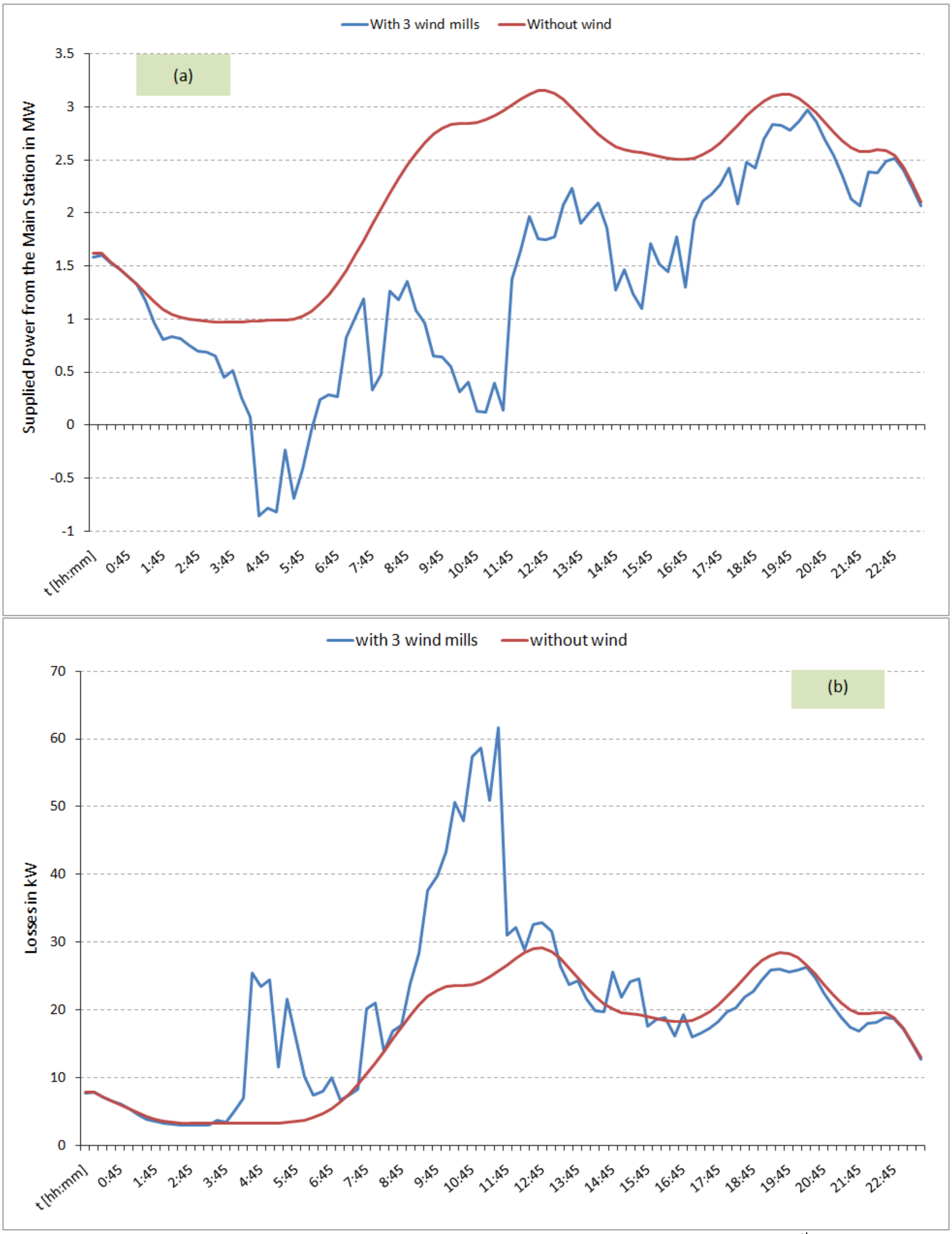

Figure 5 - 17: Supplied power from the main station (a) and losses (b) on 30th July

- ***Energy losses***

The energy losses of the system are investigated and the results for each month are presented in Fig. 5-18 compared with the losses for the case without wind. It can be figured out from these results that the losses with wind power increase in the winter season accommodating the high load which exist in this season. For the other seasons, the losses with the wind are approximately the same without wind except on July. Generally, it can be concluded that, although the wind generators are concentrated into A3 and not dispersed, the overall losses through the year is increased from 189 MWh without wind to 197 MWh with wind. That means, it is increased only by 4.2% and that is because the fluctuating nature of the wind power.

- ***Line loading***

The results which are depicted in Fig. 5-19 represent the change in the line loading before and after integration of the three wind mills. The changes in the maximum and the minimum loading in each line are plotted. It can be concluded that the minimum loading in lines of A1 is decreased by approximately 6% and that means at low load case with the existence of the wind the loads which are connected through these lines are supplied partially from the wind, while the maximum line loading in some lines in A1 is increased. These lines are the lines connecting A1 to A3 and A4. The maximum loading in lines of A3 and A4 is increased by 18-43% and that is because the small numbers of households connected in these two areas and therefore the generated power has to be transferred to the other two parts of the grid through the lines of these two areas.

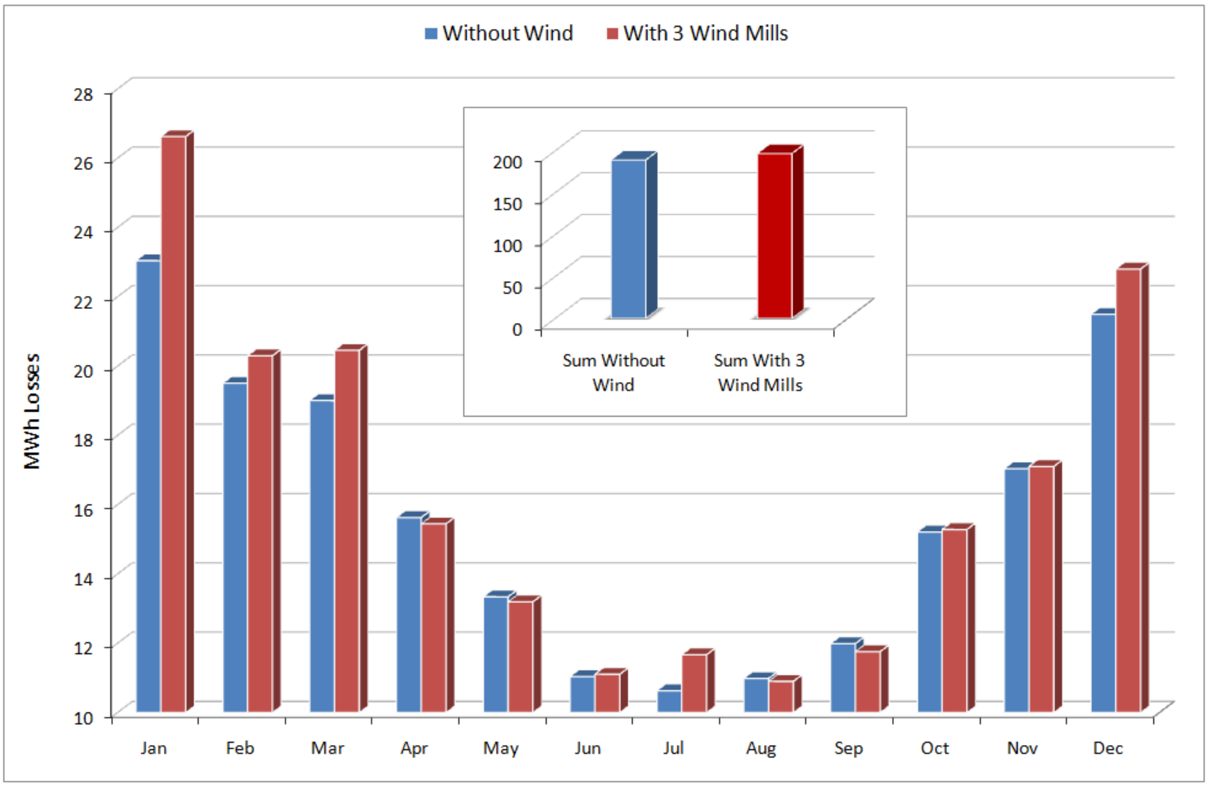

Figure 5 - 18: Monthly energy losses with and without wind mills

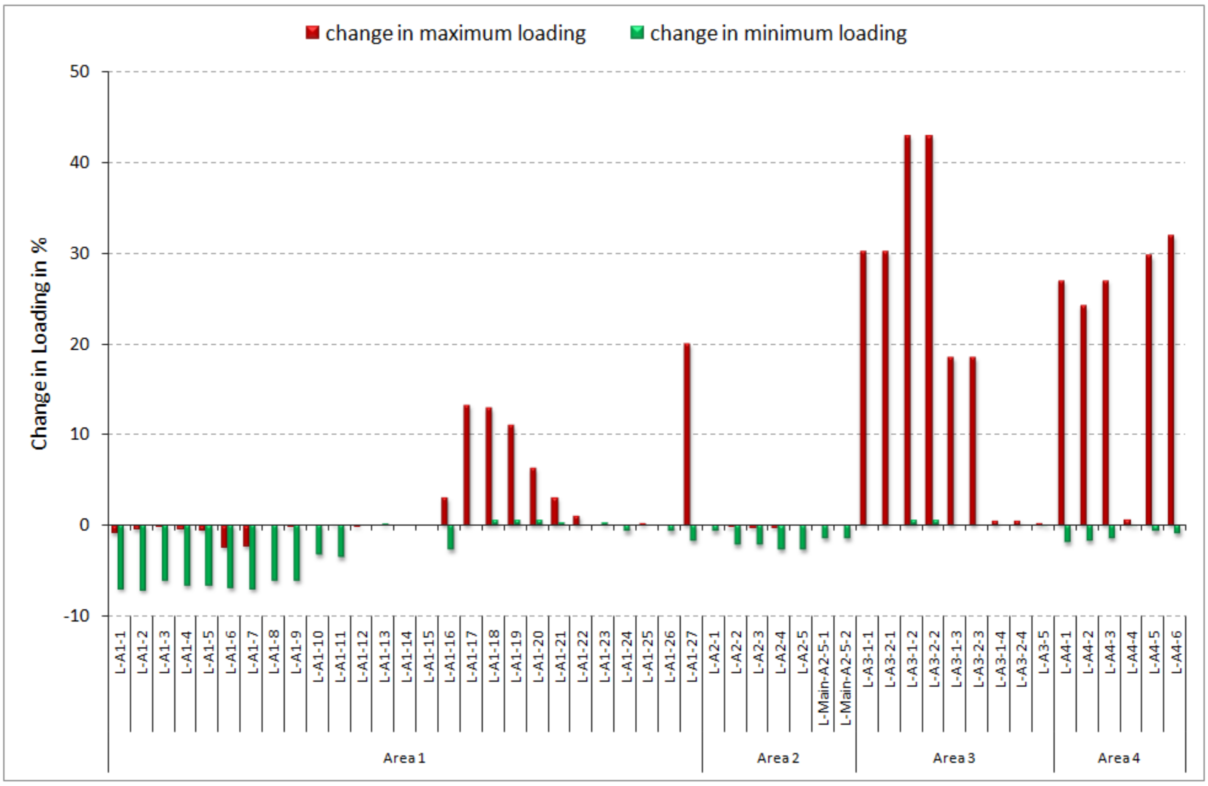

Figure 5 - 19: Change in maximum and minimum line loading with interconnection of the 3 wind mills through one year

5.3.4 Impacts of the new wind mill integration

A new 2 MW wind generator is intended to be integrated into the grid under study. There are six proposed points for connections (see Fig. 5-20) as follows:

- Three points of connection are in A3 (points 2, 3, and 4).
- Two point of connection is in A4 (points 1 and 5).
- One point of connection is in A2 (point 6)

The influences of the new wind mill interconnection on the voltage ranges, line loading and the losses of the network are investigated. The investigation is conducted by attaching the measured profile of 0.6 MW wind generator to the new wind mill. Then the availability of interconnection of the new wind mill into the grid, depending on the maximum voltage change is presented.

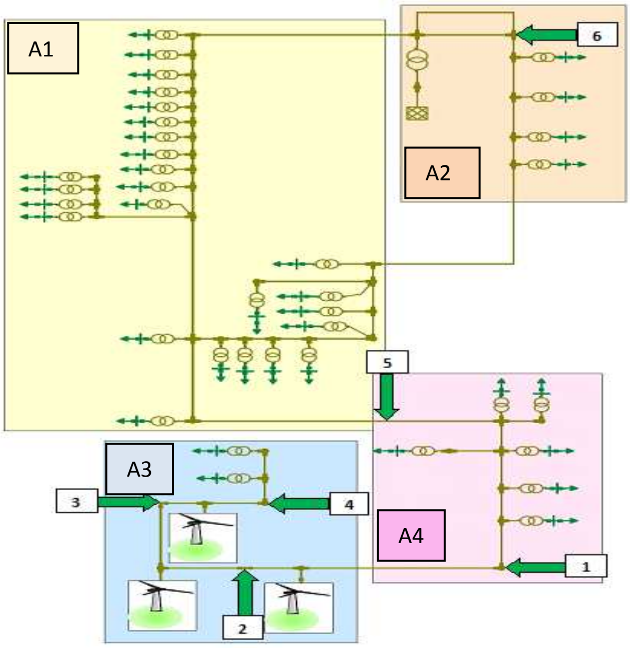

Figure 5 - 20: Proposed points of connection for the new wind mill

- ***Energy losses***

Figure 5-21 shows the energy losses through one year of the system with the integration of the new wind mill. The increasing of the losses is also depicted in the figure related to the case with the existence of three wind mills. It can be seen that the energy losses are increased when the new wind mill is integrated at all of the proposed points. It can be inferred also that point No.6 gives the lowest increase in the energy losses (7.1%), while points No.4 and No.3 give the largest increase (24.5 and 23.9% respectively).

- ***Line loading***

Considering the existence of the three wind mills as the base case, the changes in the maximum line loading are investigated with the interconnection of the new wind mill at different proposed points. The results are plotted in Fig. 5-22. It can be noticed that integrating the new wind mill at point No. 6 will not approximately change the maximum line loading of a large number of lines and decreases it in some lines of A1 by approximately 7%. While integrating the new wind mill at point No. 5 will give the same effect as the other points in its influence on the loading of A1 lines, while for the other areas it doesn't approximately change the line loading except for the lines which are connecting each two areas. The other four points increases the line loading especially in A3 and A4.

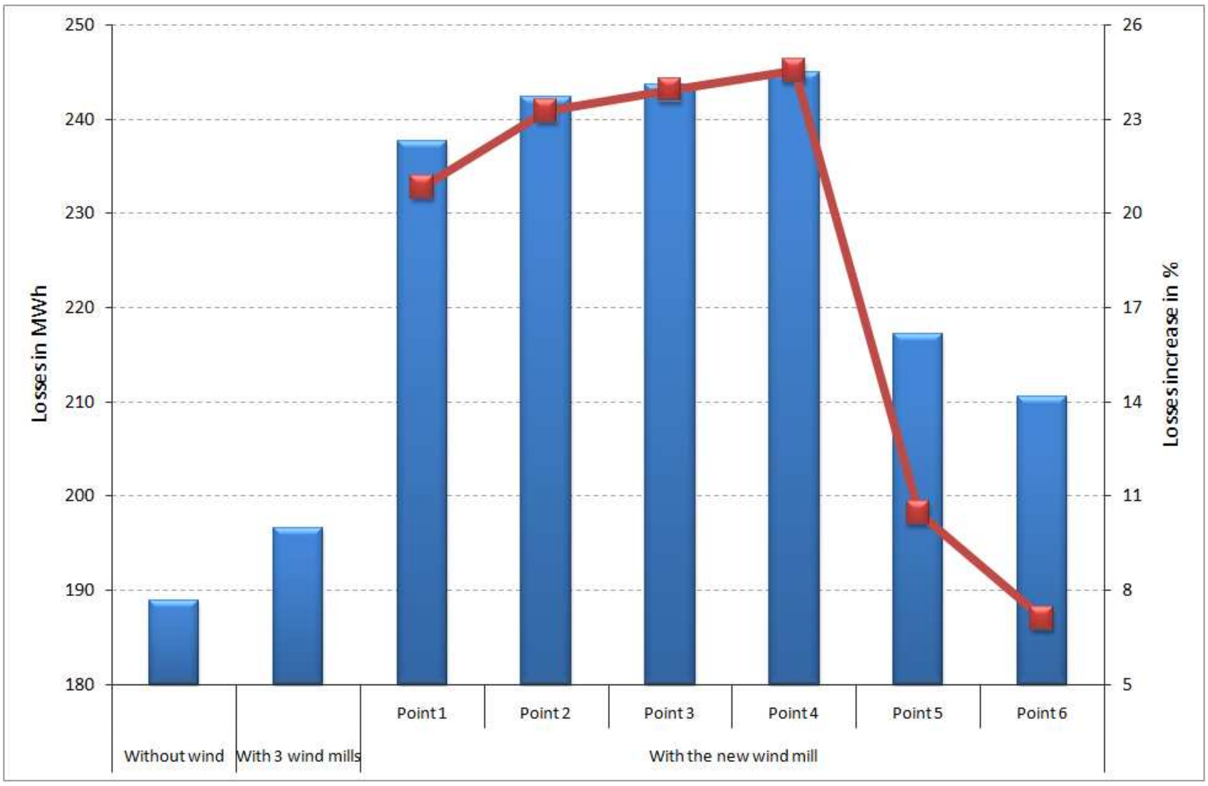

Figure 5 - 21: Annual energy losses due to the integration of the new wind mill

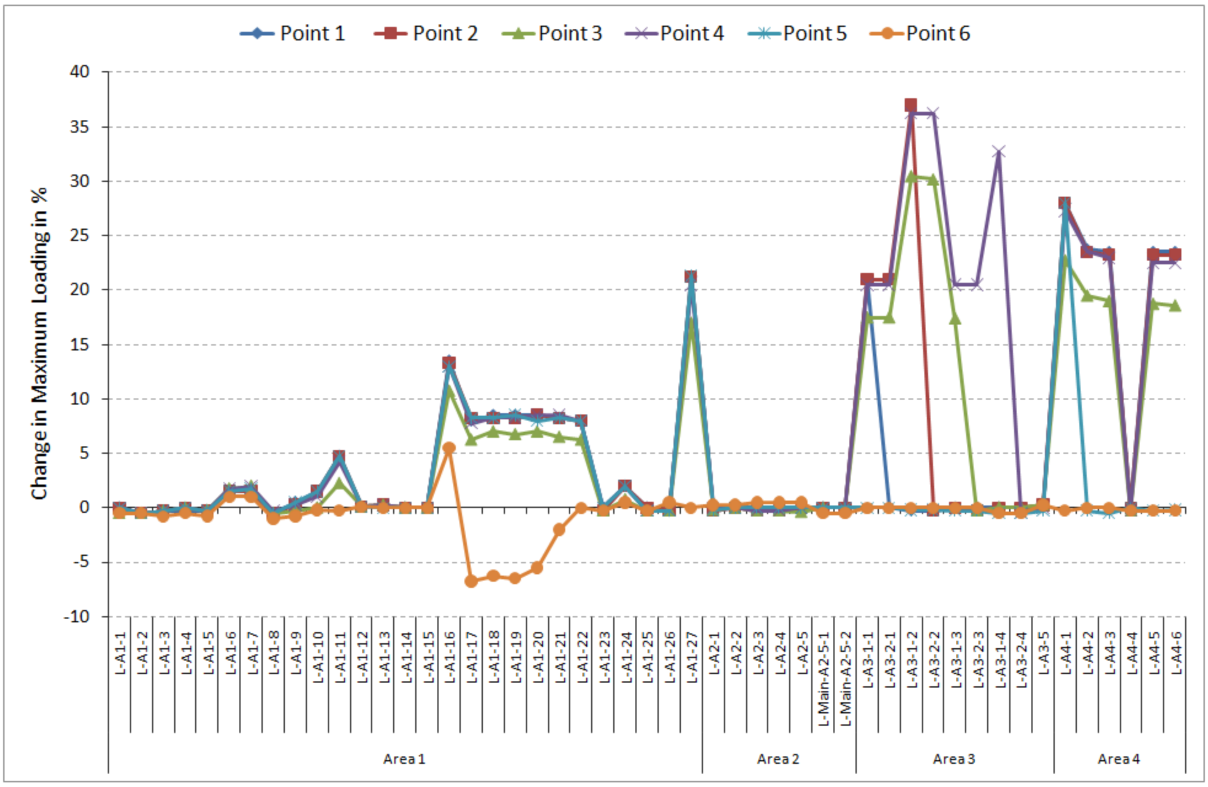

Figure 5 - 22: Variation in the maximum line loading in percentage with the interconnection of the new wind mill

5.3.5 Integration availability of the new wind mill

The German Association of the Energy and Water Industries (BDEW) introduces technical conditions for connection of generators to the MV network which specify the standards for the network operators when they intend to connect a new DG to their networks [VDE,2008]. These conditions state that it is allowed for the DG to change the voltage in the MV level only within 2%. Therefore the network under study is tested to show is that available to connect the new wind mill or not and which point is the suitable one for this issue. The maximum voltage changes in all MV nodes for all proposed points of connection related to the case of the network without wind are shown in Fig. 5-23. From this figure it can be concluded that only point No.5 and point No.6 are the two points where the new wind mill can be interconnected. While integration of the new wind mill at the other four points will change the voltages more than 2% and that is not acceptable. For more explanation, the maximum voltage change is calculated related to the case of the network with the three wind mills and the results are shown in Fig. 5-24. It can be seen that integrating the new wind mill at point No.6 will not change the voltage more than 0.4% while for point No.5 the voltage will not be changed more than 0.6%. For the other four points the voltage is changed by more than 1% at some nodes.

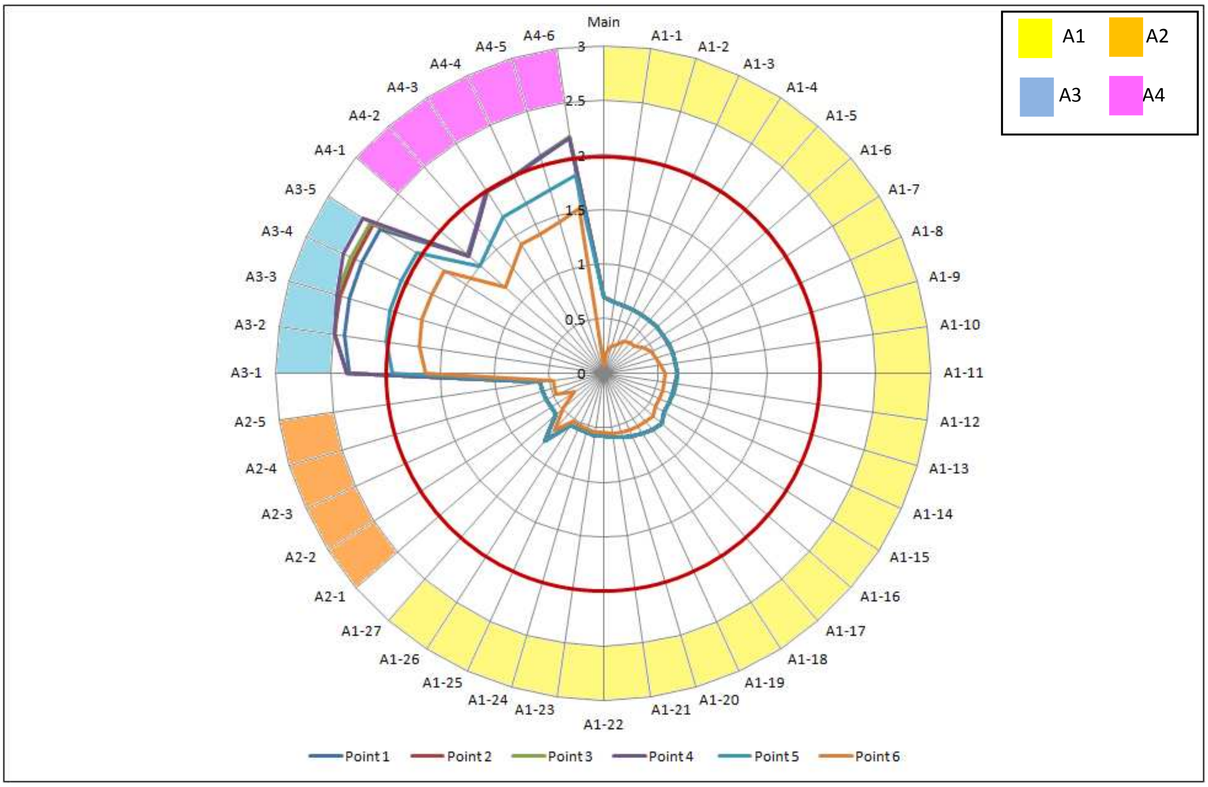

Figure 5 - 23: Maximum voltage change in percentage for all MV nodes for different points of connection for the new wind mill related to the case of the network without wind

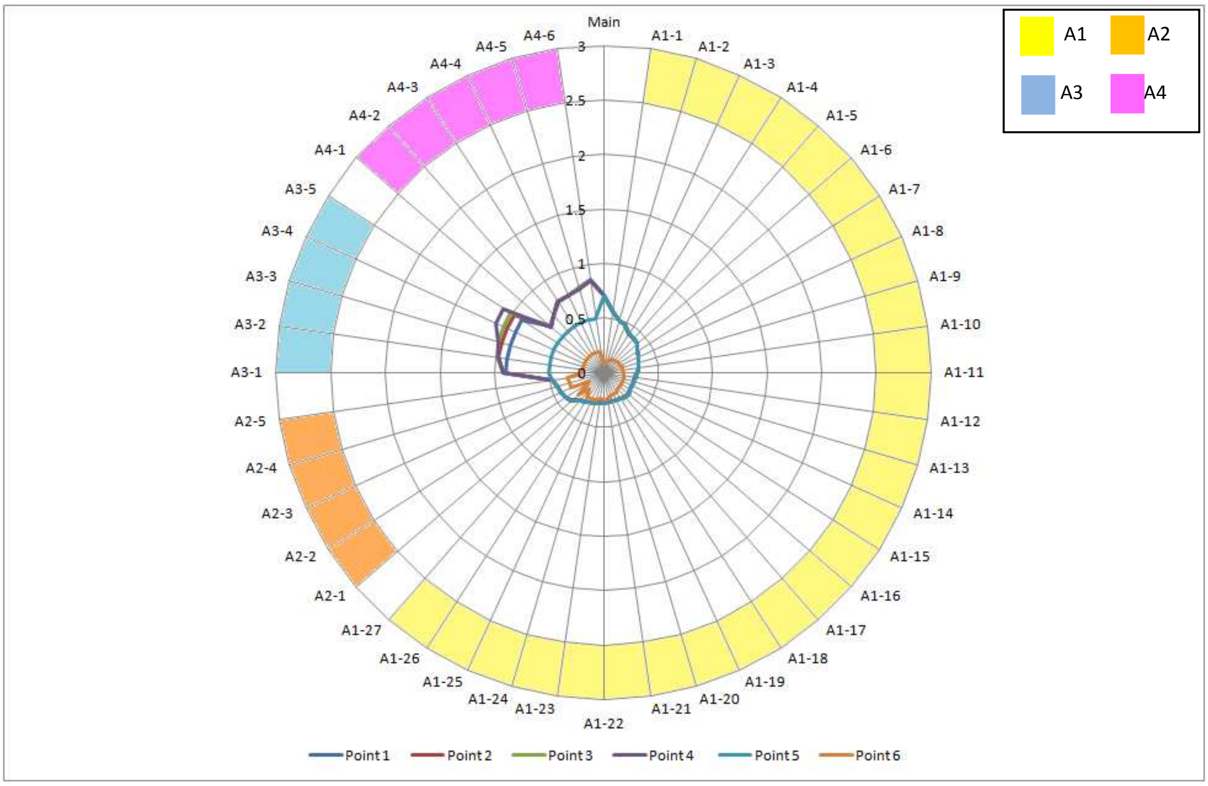

Figure 5 - 24: Maximum voltage change in percentage for all MV nodes for different points of connection for the new wind mill related to the case of the network with 3 wind mills

5.4 Summary

The implications of interconnection of integration of DWPG on a real MV distribution network have been investigated and presented in this chapter. The analysis was performed based on time series of load and wind power. The load profiles are simulated using the standard VDEW load profiles for the households. A new relation for evaluating the maximum power which can be simultaneity consumed was presented based on measured data. The network was analyzed for three scenarios which are without wind, with the existing of three wind generators and with the integration of the new wind mill. Different technical issues have been investigated to highlight the influences of the DWPG on the MV distribution networks. These issues are the voltage range, energy losses, voltage profiles, line loading, and maximum voltage change.

CHAPTER 6: RECONFIGURATION OF DISTRIBUTION NETWORKS WITH DG FOR ENERGY LOSS MINIMIZATION

Network reconfiguration is the process of changing the topology of distribution networks by changing the open/closed status of the switches. Due to the existence of many candidates switching combinations in the distribution network, reconfiguration is a complicated combinatorial constrained optimization problem [Abdelaziz et al.,2010]. Network reconfiguration is mainly implemented by the network operators for loss minimization, releasing the bottlenecks in the lines, voltage support, or system restoration [Khushalani,2006]. Different algorithms have been reported for reconfiguration of distribution networks without the presence of the DG units based on different solution methods. A small number of reported studies dealt with this problem with the existence of DG units into the distribution networks.

In this chapter a new methodology for reconfiguration of a typical MV distribution network is introduced. The load profiles at low voltage side at each MV substation are modeled using VDEW standard load profiles. The load profiles of households and commercials have been selected for the network. The proposed methodology is implemented using a combination between NEPLAN and C++ programming language. The optimization has been performed using Tabu Search (TS). The main objective of the presented methodology is the minimization of the energy losses. This accomplished through two phases, in the first phase the DG power has been assumed to be constant at different percentages of the rated power of each unit. While in the second phase generation profiles of DG have been taken into account. The results of the energy minimization, line loading, and voltage ranges are introduced for different scenarios.

6.1 Typical Network

A typical network is depicted in Fig 6-2 which has been built based on the network shown in Fig. 6-1. The DG technologies in this network are PV and CHP which are used with the given rated power at the given locations for the first part of the network. While for the other parts, the locations are changed randomly for more realistic operation of the network. All of the PV units are connected at the LV side of MV/LV transformers, while there are some CHP units are connected at the MV side and the others at the LV side. The load profiles are chosen to be households and commercials (H0 and G0). These load profiles are attached to the different loads with different percentages. Two high voltage power stations are used for supplying the power to the typical network. Maximum load for each MV/LV transformer is calculated as a percentage of the rated power in the network at 0.94 power factor. The maximum loads are taken between 20% and 80% of the transformers rated power. The number of transformers and their loading in percentage are given in Fig. 6-3.

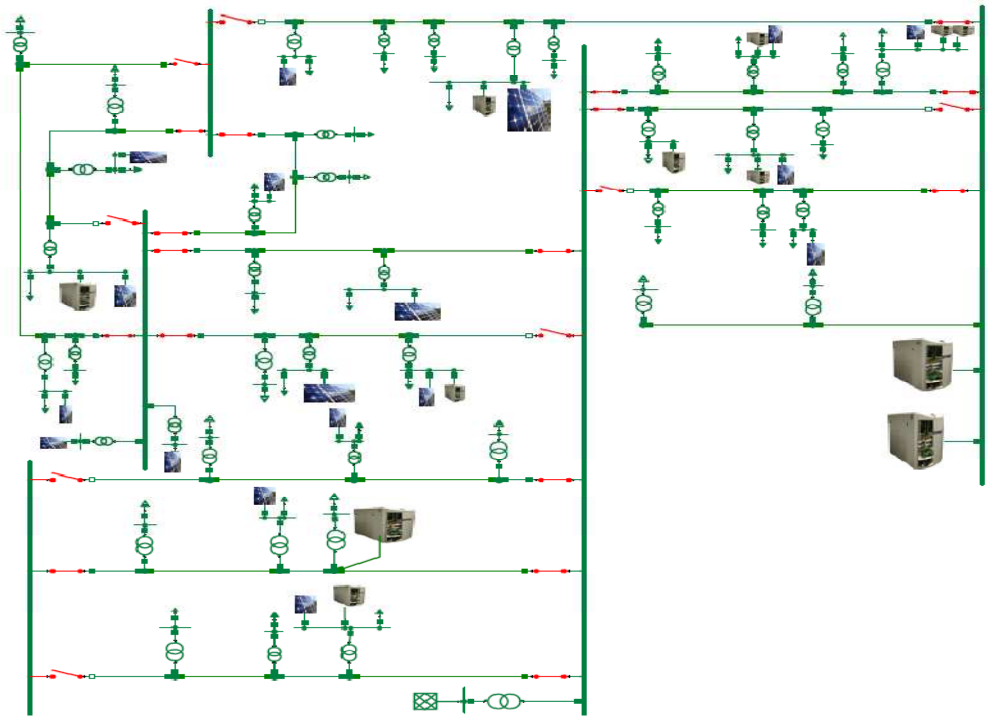

Figure 6 - 1: Loads and DG as an example in the MV network

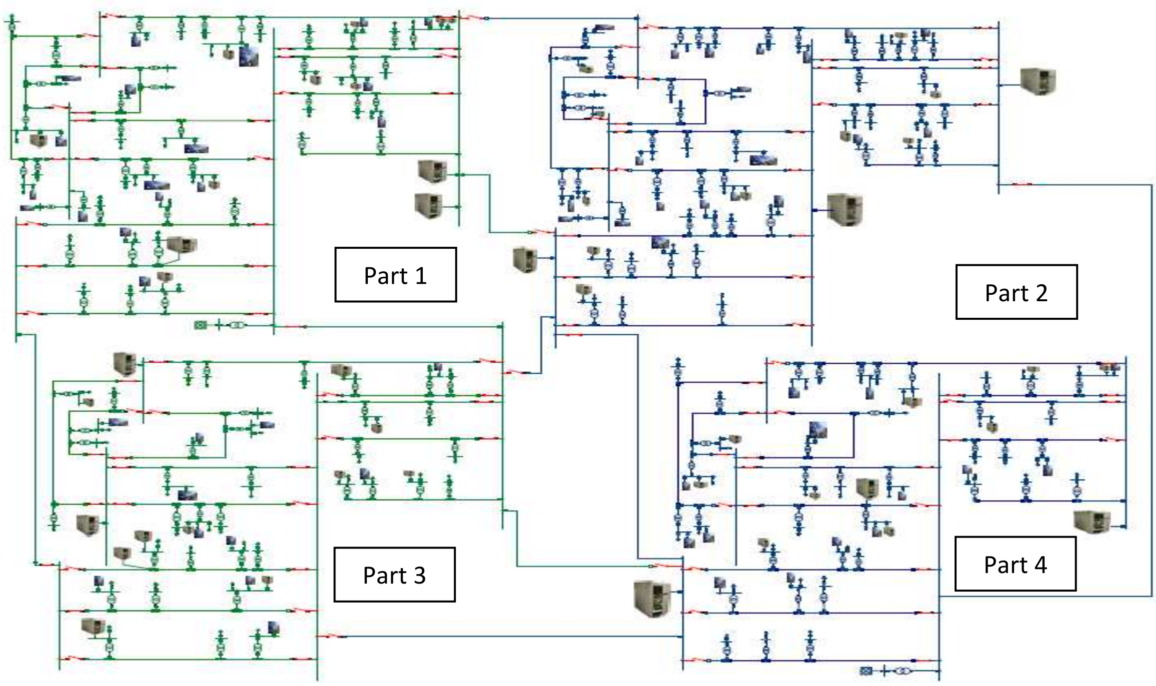

Figure 6 - 2: Typical network (initial switching state)

6.1.1 Load profiles

The VDEW households and commercials load profiles have been selected and implemented in different combinations in the simulation of the typical network. For example, 80% H0 with 20% G0, 60% H0 with 40% G0, and 100% H0 with 0% G0 have been used. The load profiles of G0 are given in Fig. 6-4 while the H0 load profiles have been already presented in Chapter 5.

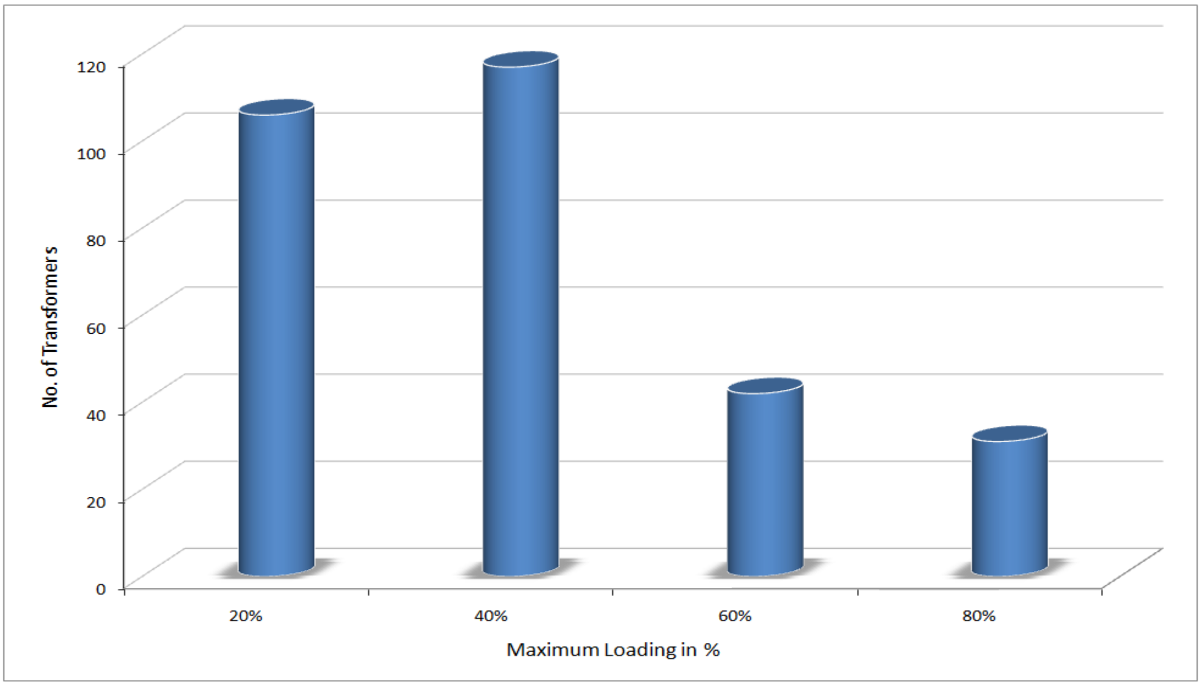

Figure 6 - 3: Number of transformers and their maximum loading in percentage

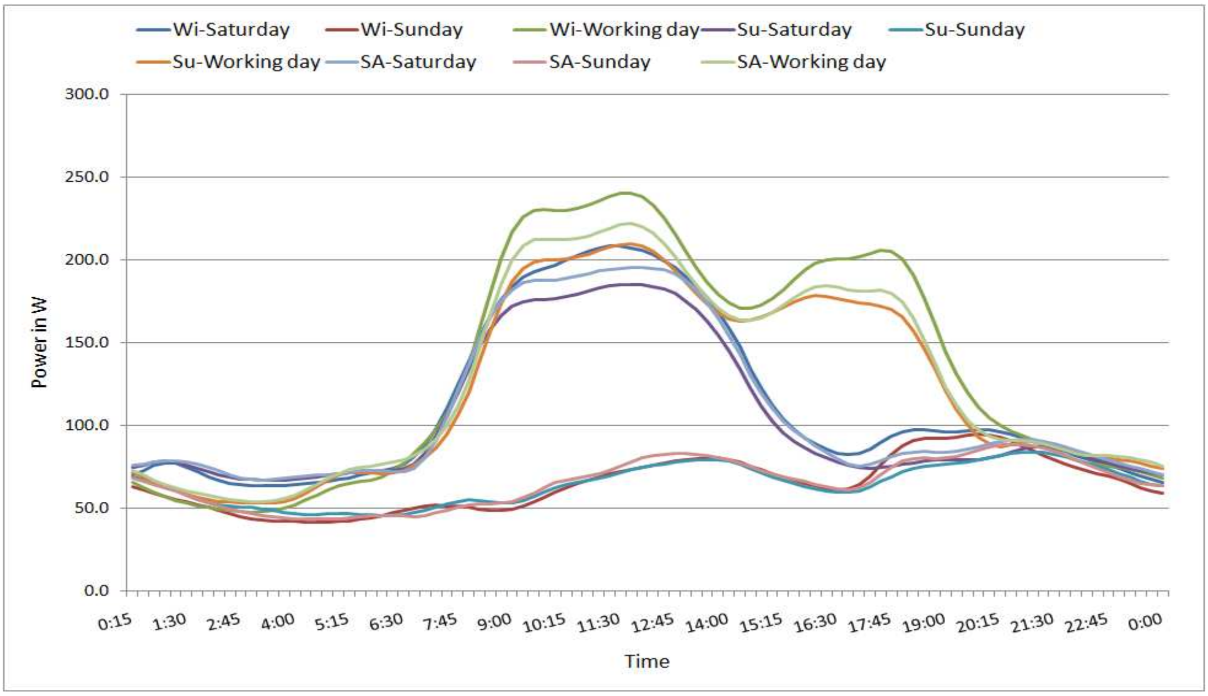

Figure 6 - 4: VDEW load profiles of commercials (G0)

6.2 Problem Formulation

In all of the reported studies two types of switches in the distribution networks are always implemented in the reconfiguration process: tie switches and sectionalizing switches. Tie switches are the switches which are used to connect different branches or feeders, while the sectionalizing switches are utilized to switch between the MV substations through the feeder. In the current study the switches at the end of the branches are only used in the reconfiguration process (see in Figs. 6-1 and 6-2). The objective of the switching state optimization is to minimize the distribution energy losses with turning these switches on/off. The reconfiguration problem has the following constrains:

- Power flow equations,
- Upper and lower limits of node voltages,
- line currents,
- Feasible conditions in terms of network topology.

Mathematically, the problem can be formulated as follows:

$$Min\ Z = \sum_{t=0}^{t=24} \sum_{k=1}^{k=l} |I_k|^2\, R_k t \tag{6.1}$$

Subject to

$$g(x) = 0 \tag{6.2}$$

$$V_i^{min} < V < V_i^{max} \tag{6.3}$$

$$I_i^{min} < I < I_i^{max} \tag{6.4}$$

Where Z is the objective function (MWh), l is the number of branches, I_k is the branch current, R_k is the branch resistance t is the time interval where the reconfiguration process is performed and $g(x)$ is the load flow equations.

6.3 Tabu Search Algorithm

Tabu Search (TS) is basically a gradient-descent search with memory. The memory preserves a number of previously visited states along with a number of states that might be considered undesired. This information is stored in a tabu list. The definition of a state, the area around it, and the length of the tabu list are critical design parameters. In addition to these tabu parameters, two extra parameters are often used: aspiration and diversification. Aspiration is used when all the neighboring states of the current state are also included in the tabu list. In that case, the tabu obstacle is overridden by selecting a new state while; diversification adds randomness to this otherwise deterministic search. If the tabu search is not converging, the search is reset randomly [Lee et al.,2008].

With the TS the optimum solution is searched through the search for the solution of a neighbor state. However, every exchange step is stored in a list, the so-called Tabu-List. As long as an exchange step is stored in the tabu list, it cannot be turned around again. It is "tabu". In order not to remain the switch, the tabu list has a limited length so that only a certain number of switches "tabu" are saved. This algorithm is ended at a given number of iterations. The advantage of the TS method is that both the local and the global solution space are covered, as can be evacuated through the tabu list local optima again. Moreover, the computational cost in comparison with the GA is low. However, here takes a parameter (length of the tabu list) influence on the solution [Mishima et al.,2005].

The TS has been selected because it depends on an initial solution, and this is valid for the networks under study, while both GA and TS are applied to the reconfiguration process of distribution networks with the existence of DG units [Choi et al.,2000b;Mishima,2005]. GA is capable of evaluating a solution near global minima. However, GA is a probabilistic search method, so it is not reliable in large systems where the solution accuracy is affected considerably by initial conditions. TS is an efficient combinatorial method that can achieve an optimal or suboptimal solution within a reasonably short time. It does not need many iteration counts to obtain better solutions. The algorithm is straightforward and deterministic so that TS is more robust than GA in terms of initial conditions. The search is performed in a more aggressive way than in the case of SA and GA. Because of these advantages, since 1999, TS optimization application to power system has been growing [Golshan et al.,2006]. Therefore, the TS algorithms successfully applied to reconfiguration of distribution networks with distributed power generation [Mishima,2005].

6.4 Solution Mechanism

In preparing the suggested algorithm the following assumptions are made:

- The branches are summarized, so that all branches are separated by switches,
- All the switches are switchable,
- Constraints of the voltage drop, the line currents, the network topology are given into the TS, so that a limited number of solutions can be searched,
- The switch states are given in a binary vector.

An optimization algorithm based on TS and switching exchange principles has been implemented in C++ and linked with NEPLAN software where NEPLAN software provides the ability to control its analysis models (e.g. load flow, load flow with load profiles, etc.) through the C++ programming language. A schematic diagram which illustrates the input data to the NEPLAN software and C++ and the investigated technical issues is shown in Fig. 6-5.

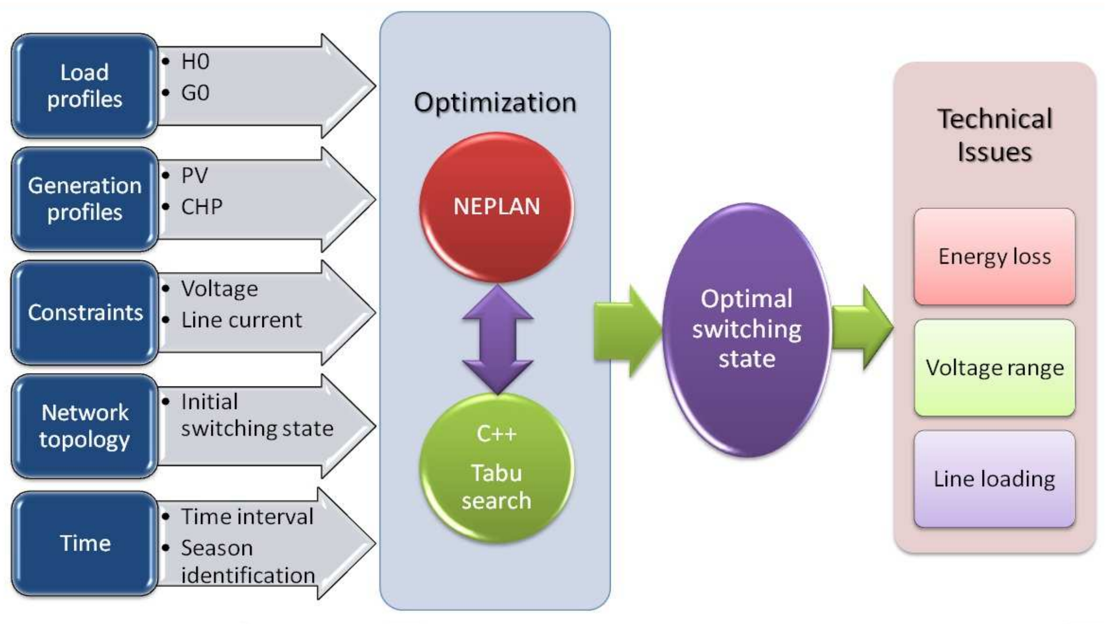

Figure 6 - 5: Solution mechanism

For more explanation of the solution mechanism a description of different phases will be discussed:

6.4.1 Inputs

- ***Load profiles***

The maximum power for each load connected at the LV side of the transformer is assigned. Then the standard load profiles combinations are given. In all of the optimization phases the load profiles are taken into consideration.

- ***Generation profiles***

The DG power was taken for the first phase of the optimization as constant percentages of the rated of each unit. In the second phase the generation profiles of PV units are given based on one year measured data provided by the utility company.

- ***Constraints***

Different constraints are taken into account in the optimization process:

- The load flow equations have to be satisfied for each solution
- All of the nodes have to be energized
- No interconnection between the two HV stations
- The voltages have to be kept within the acceptable limits
- The line loading has to be kept within the limits

- Radiality of the network when the optimization is searching for an optimal radial network.

- ***Network topology***

The network structure has been built into NEPLAN platform. This typical network was built based on real data for a MV network in Germany. Load flow with load profile simulation was used into the optimization algorithm to evaluate the energy losses for each solution. To identify a switch state, a binary identification was used, where 0 was taken for off switches and 1 was taken for on switches. The initial switching state of the network has to be given in binary manner in the C++ code.

- ***Time***

Using the load flow with load profile simulation the time interval has to be specified. In the current study this time interval was taken as one hour to reduce the time consumed to perform the optimization. On the other hand, to fulfill the voltage limits, only load flow has to be performed, however in this case without load profiles. Therefore, the maximum power for each load has to be multiplied by a certain value represents the season. This was given in the C++ code.

- ***Optimization algorithm***

In this part the sequence of different steps in the optimization algorithm (see Fig. 6-6) will be discussed. The initialization process is performed first by determining the initial solution (A), through the evaluation of the energy loss of the network using the initial switching state. Then an empty tabu list is created and the number of iterations is set to be = 0. The minimum energy loss is then set to be equal to (A) which is taken as the current solution. The iterations then started with check of the number of iteration. After that an identification of the neighborhood of X (switch) by Branch Exchange is performed. Then the change is evaluated through the load flow with load profiles which is implemented in NEPLAN. Then the best neighbor switch (Y) to be changed is identified. Then the new solution is compared to those which are existed in the tabu list and the tabu list is updated as the new solution is less than the current solution. This process is continued till the maximum number of iterations is reached. Then the optimal switching state and the minimum energy loss are given.

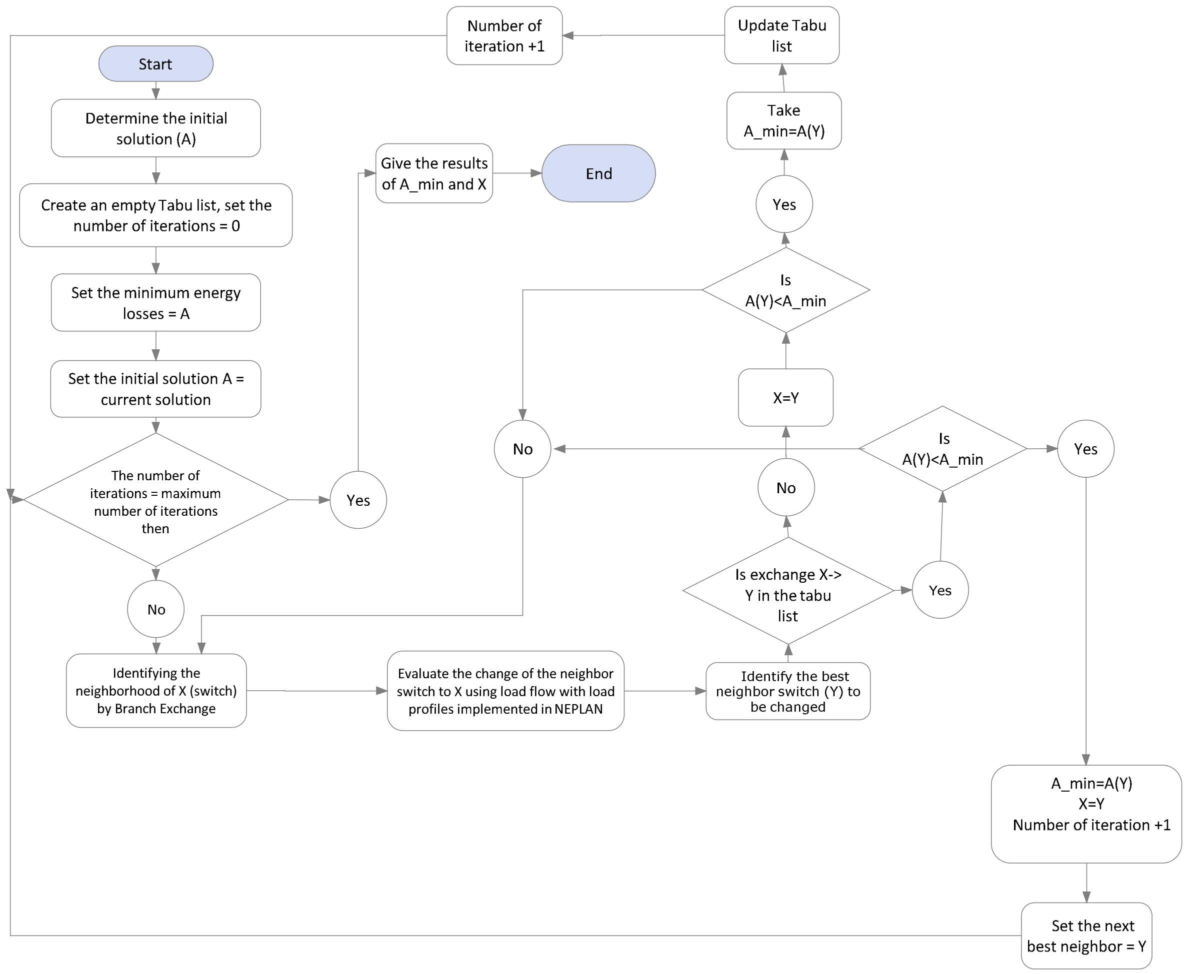

Figure 6 - 6: Proposed algorithm

After obtaining the results in a txt file, different technical issues have been investigated such as energy losses, voltage ranges, and line loading. In the next section the results of implementing the proposed algorithm on the typical urban network for different scenarios will be discussed. The results of the first phase will be discussed first where DG power without profiles are taken into consideration, then the second phase where the DGs were taken with profiles.

6.5 Implementation of the Optimization Algorithm

The optimization has been conducted in two phases in the first phase only the load profiles are taken into account while the DG power is taken to be at a constant at different percentages of the rated power, i.e. 0, 50%, and 100%. As the initial switching state was randomly selected the objective function which is the energy loss is minimized and then maximized. Therefore the potential of implementing the new methodology in reducing the energy losses can be evaluated through the year. Three seasons have been considered, winter, summer, and the two other seasons are considered as one season. Three days in each season were investigated working day, Saturday, and Sunday. Like this the optimization was conducted for 27 days for minimization and 27 days for maximization. In the second phase the load and DG profiles are taken into consideration. The two DG technologies which exist in the network under study are CHP and PV. The CHP units are considered to supply its rated power all over the day, why the PV profiles are taken into consideration. Therefore the days are classified into sunny, cloudy and rainy. The optimization was conducted in three seasons in different day types. Figure 6.7 shows the optimization phases.

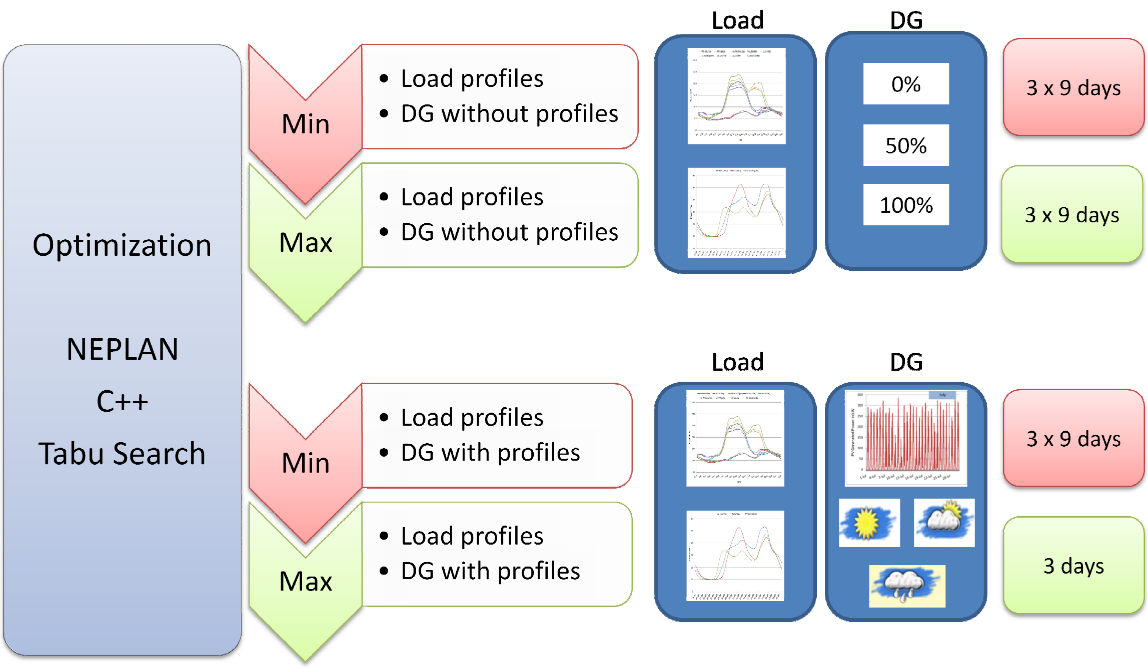

Figure 6 - 7 : Implementation of the optimization algorithm in different cases

6.6 Results

The proposed algorithm has been implemented to reconfigure the typical network for minimizing the energy losses. As the initial switching state which has been selected to perform the optimization process is a random case, the algorithm is used to maximize the objective function, i.e. energy losses while all the constraints are kept within the specified limits. Maximization helps also in evaluating the potential behind the reconfiguration.

6.6.1 DG without profiles

In this phase of the work, the DG power has been taken as constant percentage of the rated power e.g. 0%, 50%, and 100% for the whole tested day. The switching state of the typical network in nine days has been optimized; these days are identified as follows:

- Wi-Working day, Wi-Saturday, Wi-Sunday,
- Su-Working day, Su-Saturday, Su-Sunday,

- SA-Working day, Su-Saturday, Su-Sunday.

The minimization and maximization were performed starting from the initial random switching state. The results of the reconfiguration on the variation of the energy losses, voltage ranges, and line loading are introduced in the next subsections.

- ***Optimal Configurations***

The optimal switching state for a Su-Saturday with 50% DG as an example has been checked and it has been observed that after changing the state of 34 switches in the network three branches in part 2 are supplied from the main transformer located at part 1. Moreover, that the large CHP unit which is connected at the left side of part 4 is switched to supply its power to part 3. Also, CHP unit which is connected at part 2 is switched to supply its power to part 1. This means that the reconfiguration with the existence of DG units do not affect the direction of power flow to the load but affect the power flow from the connected generators. As one of the constraints that each main transformer has to be separated from the other one, it can be said that the optimum switching state is not occurred through the switching inside the region supplied by a certain main transformer, but by interconnection between them.

- ***Variation in the energy losses***

Figures 6-8 and 6.9 show the variation in the energy losses for the investigated days using maximization and minimization, respectively. The minimization and maximization process have been conducted for all DG percentages 0%, 50%, and 100%. Without DG, i.e. 0% DG the energy losses have been reduced within the range of 18.6% to 19.2% while, with 50%DG, the losses have been decreased within the range of 16.2% to 17.6%. Furthermore, with 100% DG, the energy losses were minimized within the range of 13.6% to 15.2%. The same initial switching state has been used for all DG penetrations and it was observed that the losses have been decreased as the DG penetration is increased. This can be explained as the DG units are dispersed through the network giving the chance for the DG power to be consumed locally and therefore the losses are already decreased with the existence of the DG. For example, the energy losses of the initial switching state for a Wi-Working day are 5.6, 4.64, and 3.9 MWh with 0%, 50%, and 100% DG power, respectively. These values are minimized to 4.6, 3.87, and 3.33 with 0%, 50%, and 100% DG power, respectively. From the minimization results, it can be inferred that the ability to minimize the energy losses is reduced as the DG penetration increased from 0% over 50% to 100% DG. Comparing the minimization and maximization results, it can be observed that the initial switching state lies at different distances from the minimum and maximum energy for each day and different DG penetrations. Therefore, it can be said that for each DG power and each load value there is a certain optimum switching state. This clarifies the importance of taking the generation profiles into consideration through the optimization process. The annual potentials for different scenarios have been evaluated based on the number of each investigated day in the year 2009. These potentials are also evaluated related to the initial and maximum energy losses. The annual potential results are shown in Fig. 6-10. It can be observed that using the presented algorithm, a minimization of approximately -51.4%, -44%, and -44.4% can be obtained for 0%, 50% and 100% DG power, respectively.

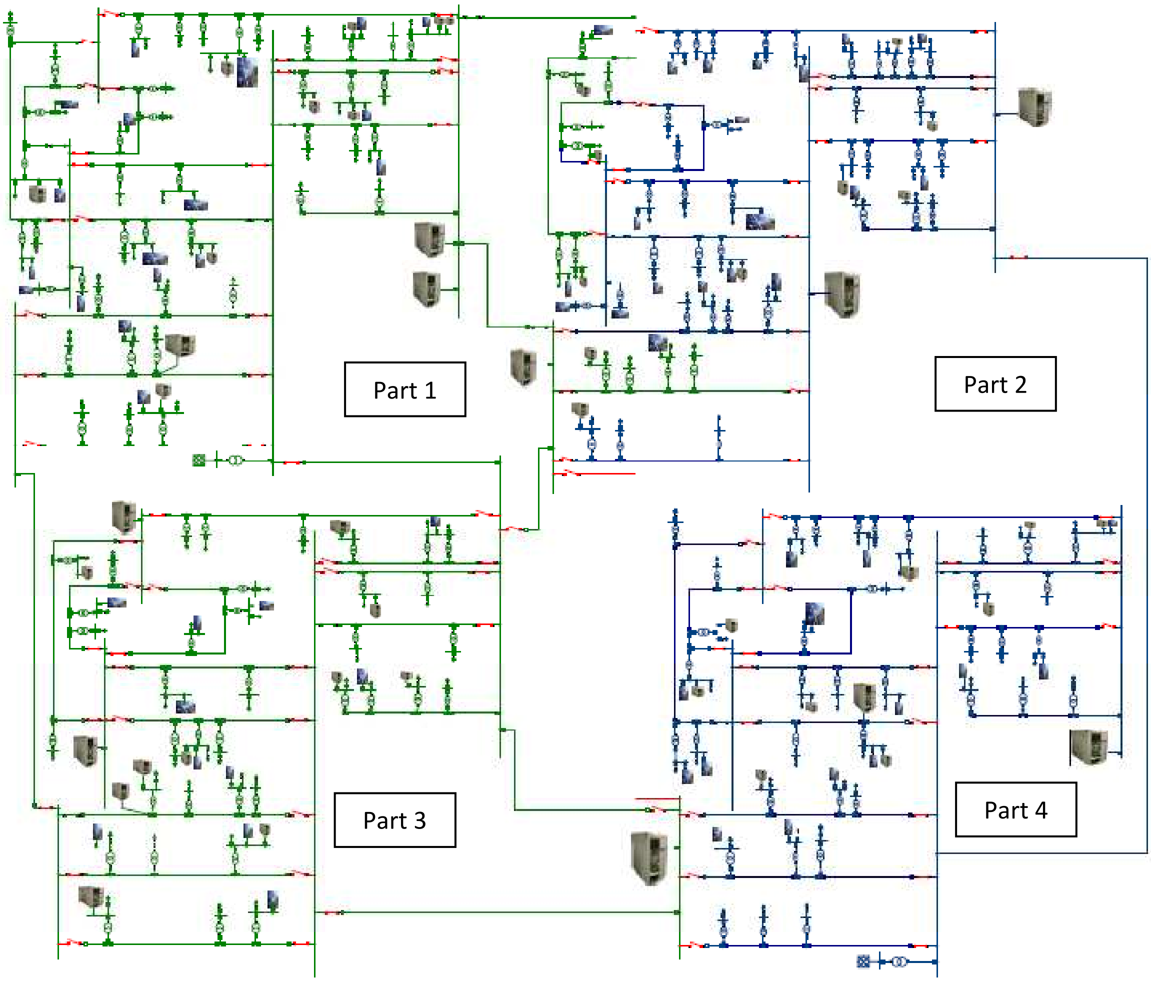

Figure 6 - 8: Optimum switching state for 50% DG on a Su-Sa

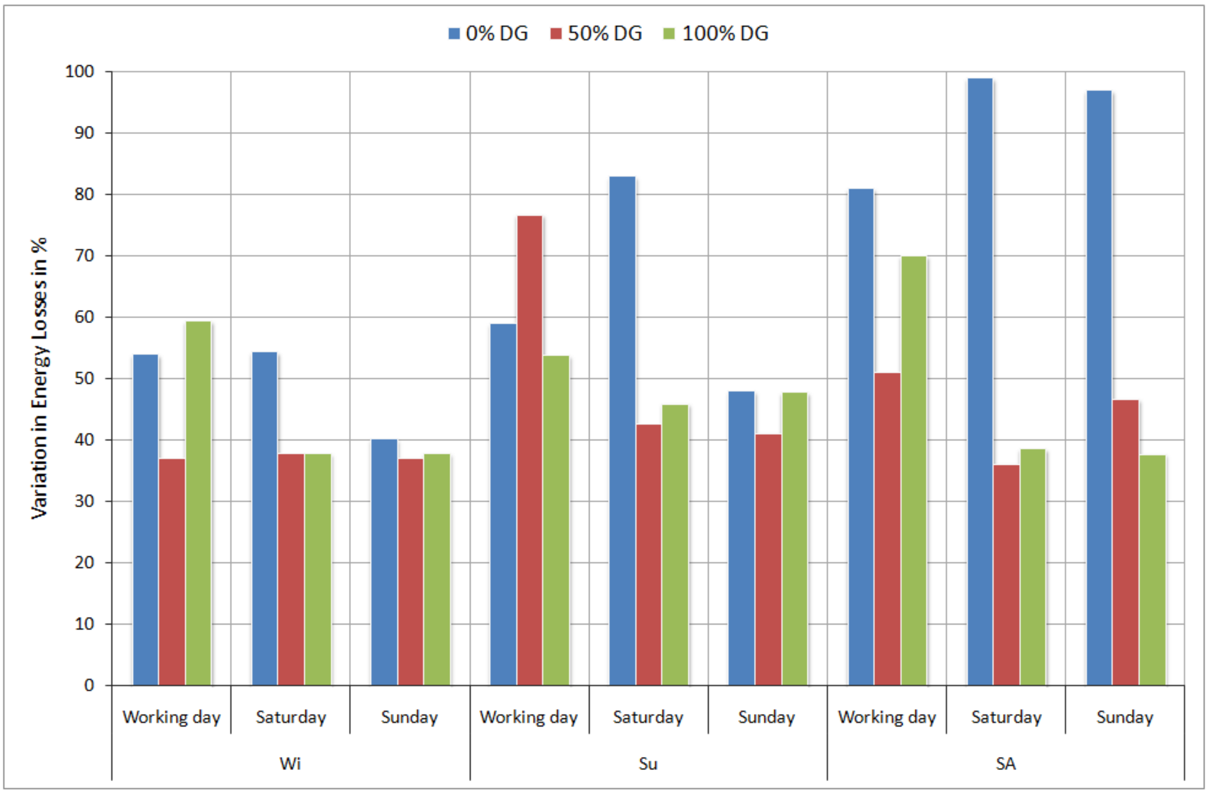

Figure 6 - 9: Variation in the energy losses in percentage for different investigated days using maximization

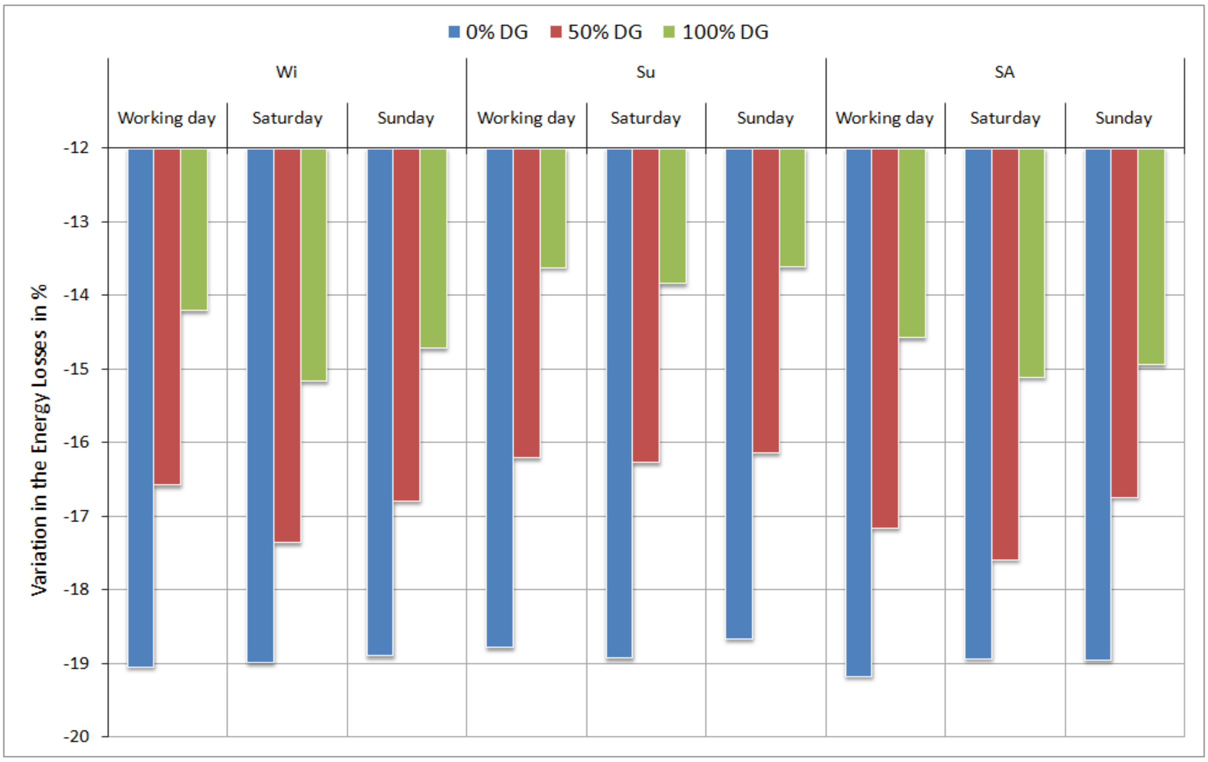

Figure 6 - 10: Variation in the energy losses in percentage for different investigated days using minimization

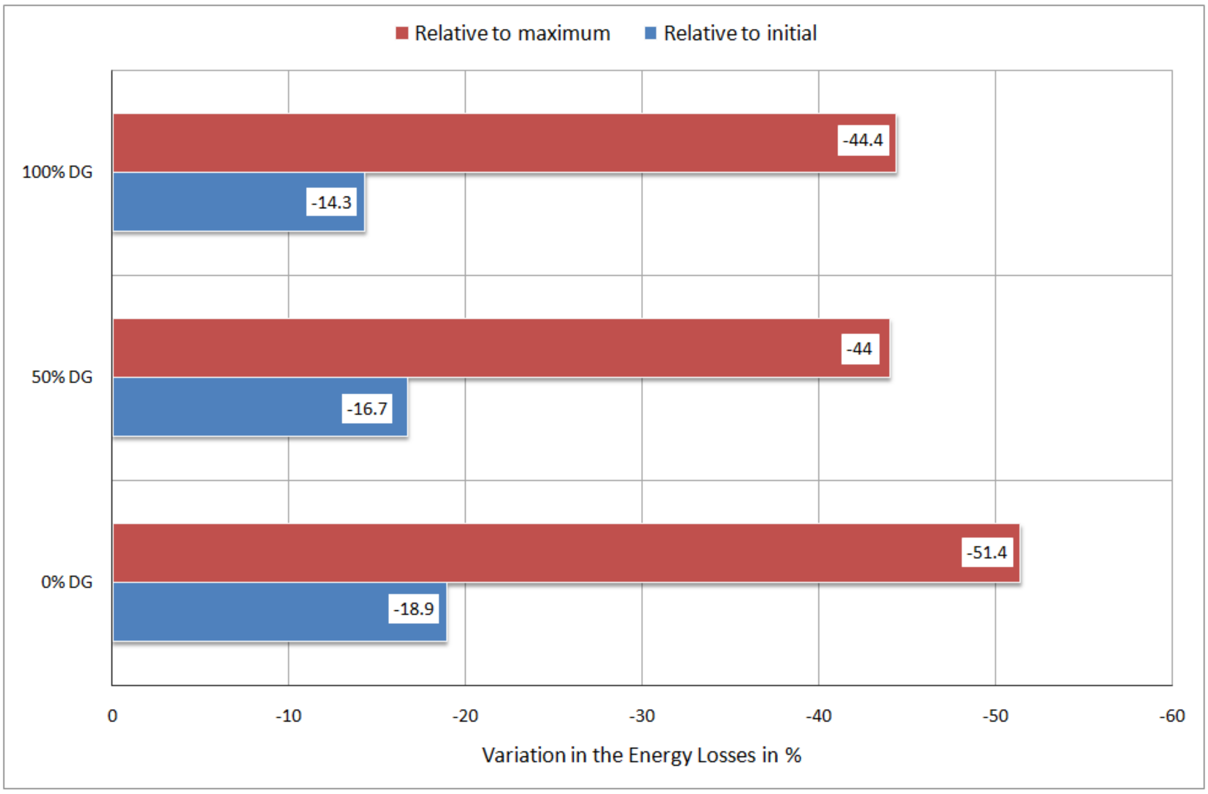

Figure 6 - 11: Annual potential in energy losses minimization relative to the initial and maximum values

- ***Voltage ranges***

The voltage ranges of the typical network all over the investigated nine days for switching state of maximum, initial, and minimum energy losses for all DG penetration scenarios are given in Fig. 6-12. It can be observed that there is an improvement in the voltage range by implementing the presented algorithm. For the maximum energy losses, the voltage ranges from 95.2% to 100.7% while for initial switching state the voltage ranges within 97.2% to 100.6%, and for the minimum energy losses switching state ranges within 98.3% to 100.5%. As small as the voltage range the voltage quality increased, or by another meaning that the variation in the load hasn't a significant impact on the voltage change.

- ***Line loading***

The line loading is significantly affected by many factors through the optimization such as: switching loads from one feeder to another, changing the direction of the power flow, and transferring the DG power (especially large ones) from certain part or branch to another. These aspects are found in the results of the lines loading shown in Fig. 6-13. For example; the maximum line loading for switching state of the maximum energy losses approaches 98% while the maximum line loading for optimum switching state is approximately 45% all over the investigated days.

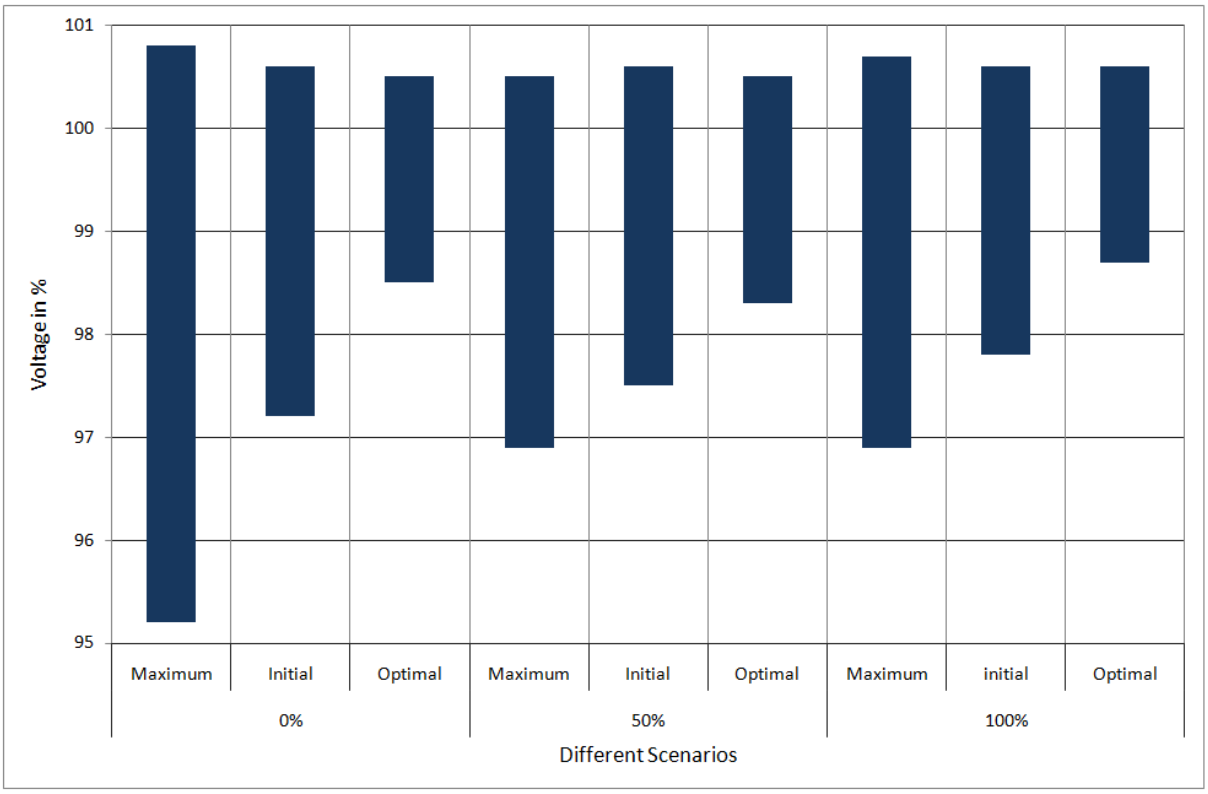

Figure 6 - 12: Voltage ranges of MV nodes for different scenarios for switching state of the maximum, initial, and minimum energy losses

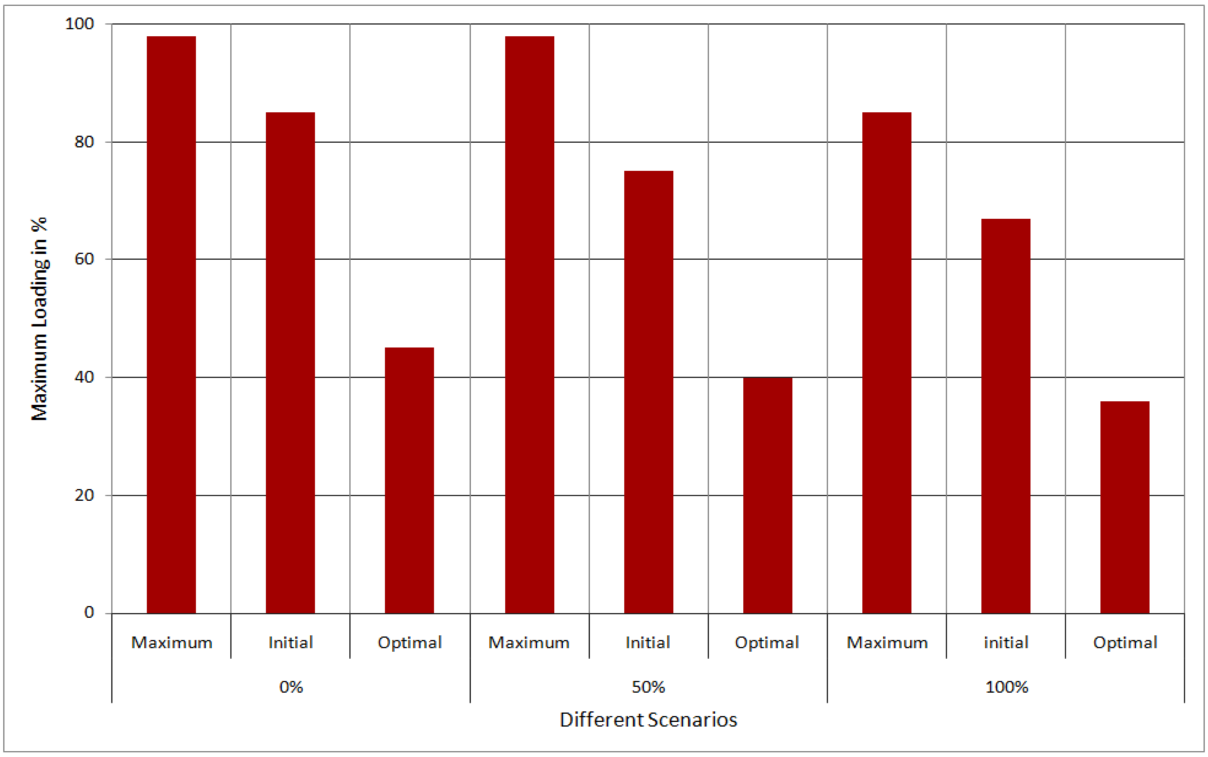

Figure 6 - 13: Line loading for different scenarios for switching state of the maximum, initial, and minimum energy losses

6.6.2 DG with profiles

- ***Day's classification***

In this phase of the study, the reconfiguration process is conducted taking the DG profile into consideration. For the CHP units the generated power has been taken constant for the whole investigated day through the optimization, while the PV generation profiles are taken into consideration. Measured generation profile of PV generations has been implemented. These profiles have been integrated in the NEPLAN model. Without the DG profiles, the investigated days have been specified based only on the day type and the season of the year. However, with DG profiles the investigated days are specified based on the day type, the season, and the energy supplied from the DG unit. Regarding the DG (which is PV in this case) energy supplied, for each day type within a certain season, there are three available scenarios which are sunny, cloudy, and rainy. This criterion is illustrated in Fig. 6-14, where the different generation scenarios are defined according to the total energy supplied from the PV units. The number of the investigated days in this case is 27 and the following are some examples which clarify the day's classifications:

- Wi-Working day-Sunny, Wi-Working day- Cloudy, Wi-Working day- rainy
- Wi-Saturday-Sunny, Wi- Saturday - Cloudy, Wi- Saturday - rainy
- Wi-Sunday-Sunny, Wi- Sunday - Cloudy, Wi- Sunday - rainy

The investigated day for each scenario is always selected to be at the middle of the number of the selected type. For example, for the summer working days there are 45 sunny days, so that 12 June is selected to represent the Su-Working day-Sunny because it is the day number 23 of 45 days. This day is illustrated in Fig. 6-14 by a black point.

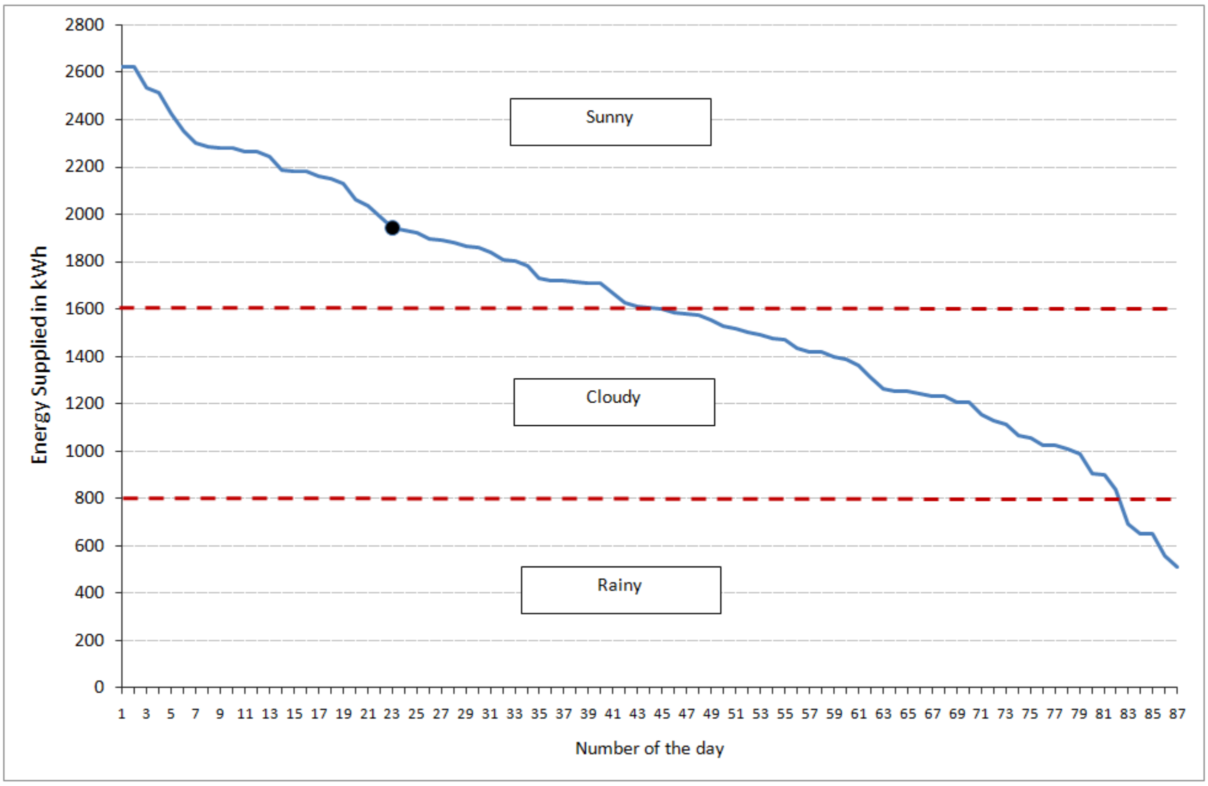

Figure 6 - 14: Day specification based on the supplied energy for summer working days

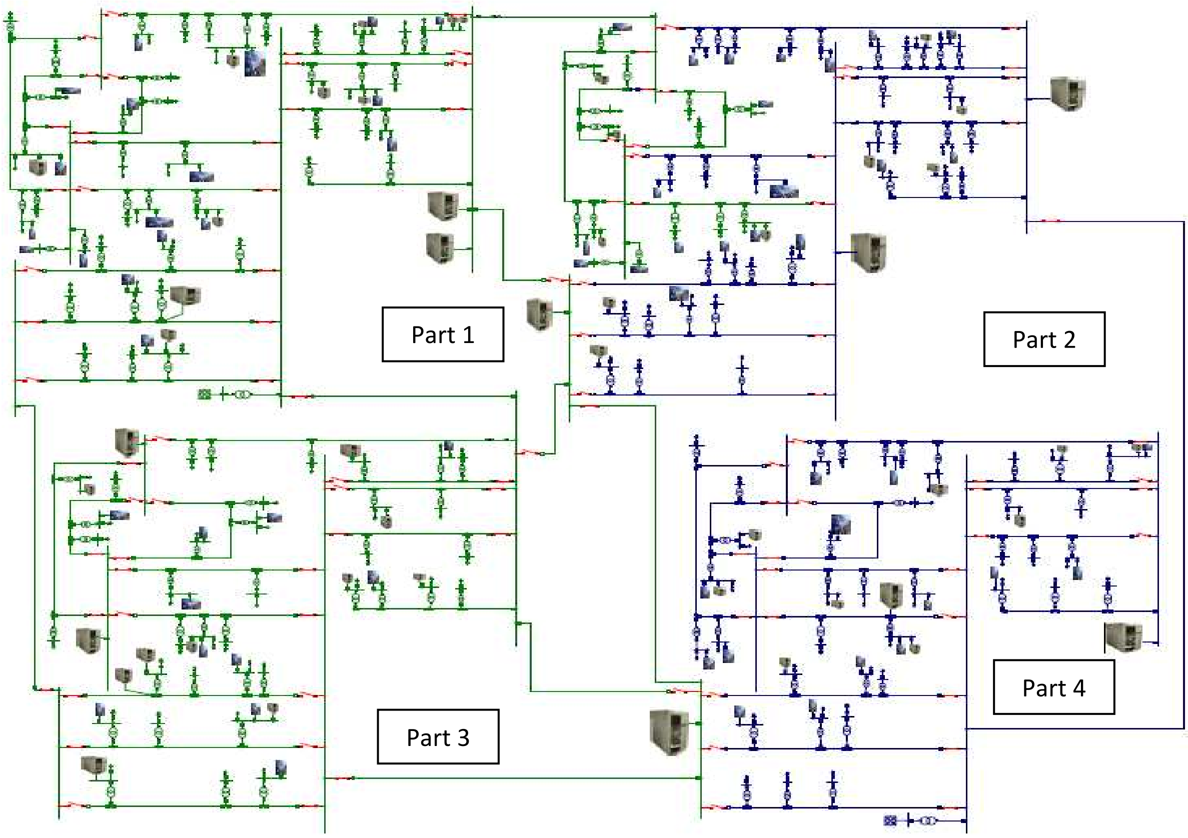

Figure 6 - 15: Optimum switching state for a Wi-Saturday-Rainy

- ***Optimal Configuration***

The optimal switching state of the network for a Wi-Saturday-Rainy (see Fig. 6-15) as an example has been checked and it has been observed that four branches in part 2 are switched to be supplied from the main transformers in part 1. An interesting observation is that the two large CHP units in parts 2 and 4 are switched to supply their power into part 2 not to part 1 where the main transformer is connected. Therefore the CHP unit, which is connected in part 2, is switched to supply its power to part 3 through a node in part 4.

- ***Variation in the energy losses***

The proposed algorithm was implemented to optimize the switching state of 27 days taking the load and generation profiles into consideration. The results of the energy variation relative to the initial switching state in percentage are shown in Fig. 6-16. By applying the classification criterion it has been found that there is no sunny Wi-Sunday, so that no results can be found for this day. The results show that relative to the initial energy losses, the presented algorithm can minimize the energy losses within the range between 13 to 16%. By the same methodology which is applied to minimize the energy losses in the first part, the energy losses were maximized starting from the initial switching state. In this case only three days were selected to perform the maximization. These three days have the maximum energy losses among the nine days in each season. The results of the maximization in percentage are 23.4%, 46.3% and 40.2 for Wi-Saturday-Rainy, Su-Saturday-Cloudy, and SA-Saturday-Sunny, respectively. The annual reduction in the energy losses based on the initial and maximum energy losses have been evaluated and the results are shown in Fig. 6-17. It can be seen that the energy losses can be reduced by approximately 15% and 49% relative to initial and maximum energy losses, respectively.

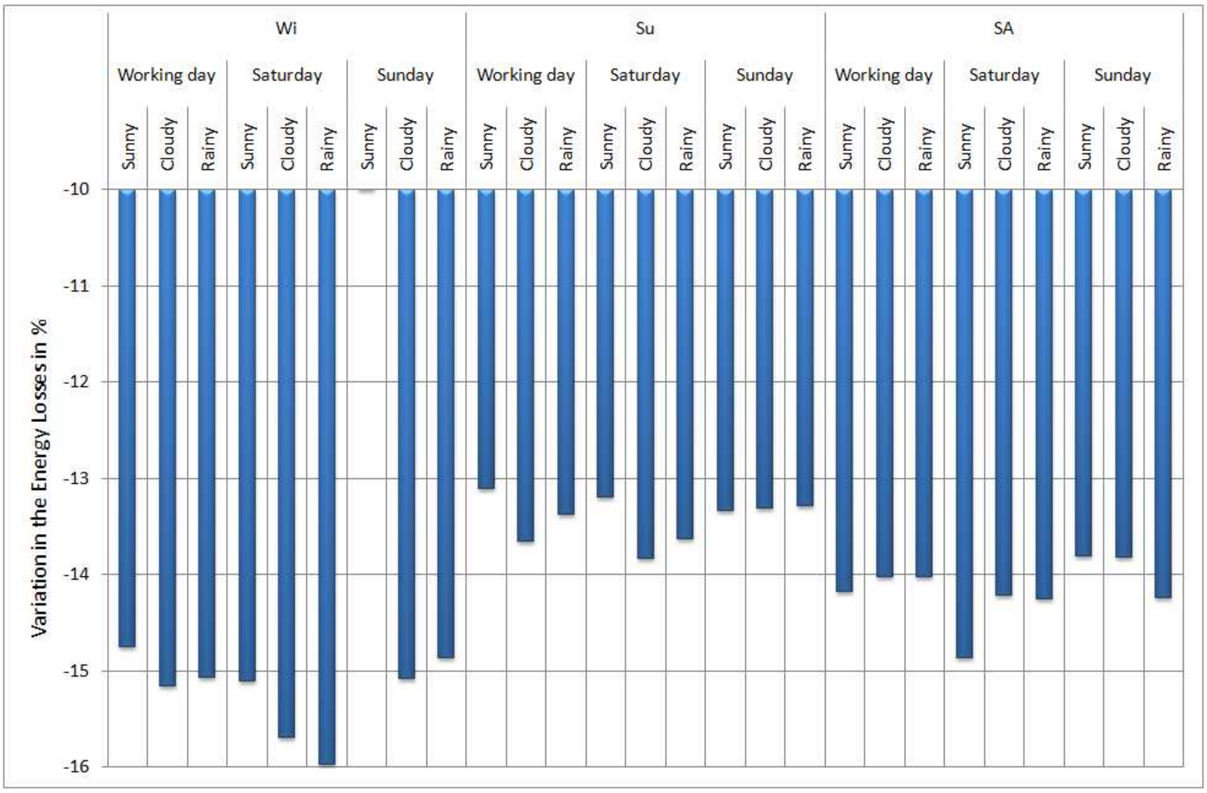

Figure 6 - 16: Variation in the energy losses for different investigated days

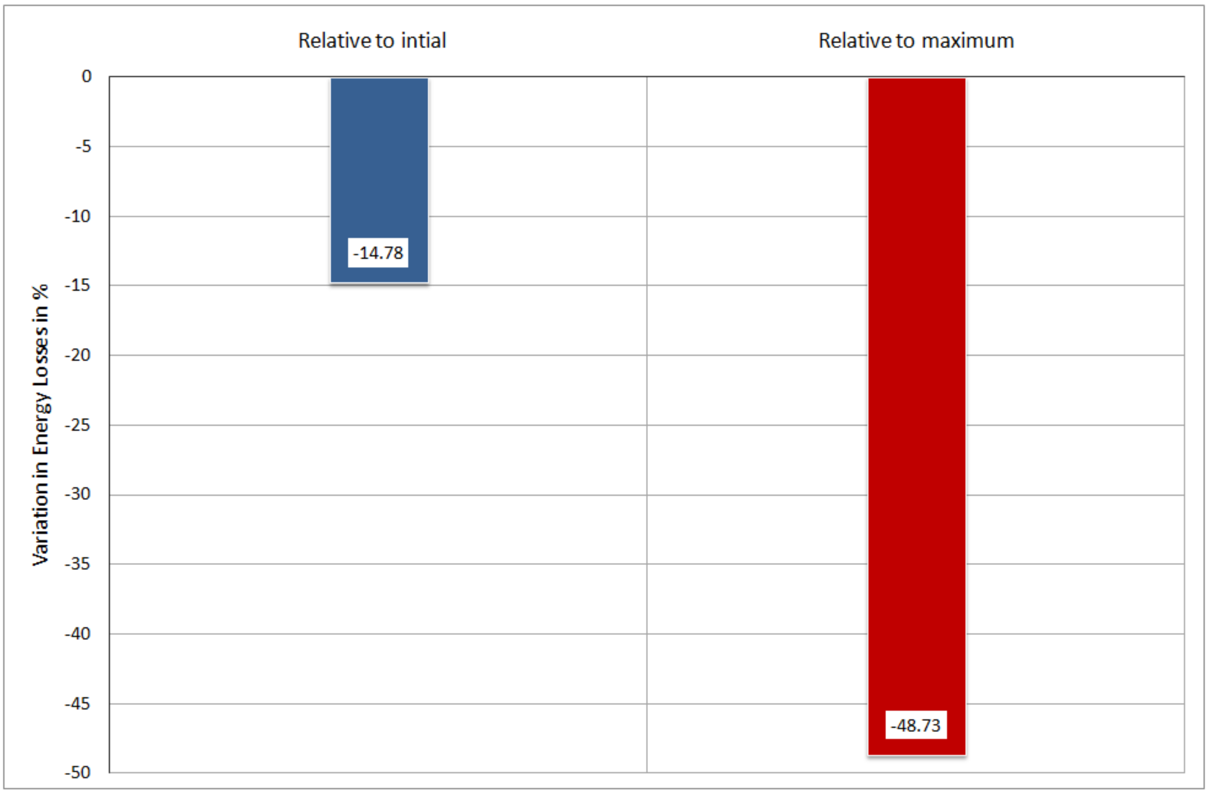

Figure 6 - 17: Annual reduction in the energy losses relative to initial and maximum switching states

- ***Voltage ranges***

The voltage ranges all over the MV nodes for all investigated days, regarding the maximum and minimum energy losses are shown in Fig. 6-18. It can be seen that the voltage ranges within 97.3% to 100.4% for the switching state of the maximum energy losses. While, the voltage ranges within 98.5 % to 100.5 for the switching state of minimum energy losses. This confirms the voltage improvement through the reconfiguration process.

- ***Line loading***

The maximum loading all over the lines for the case of maximum and minimum energy losses are given in Fig. 6-19. It can be seen that the maximum loading is reduced from 90% to 42% through the optimization process.

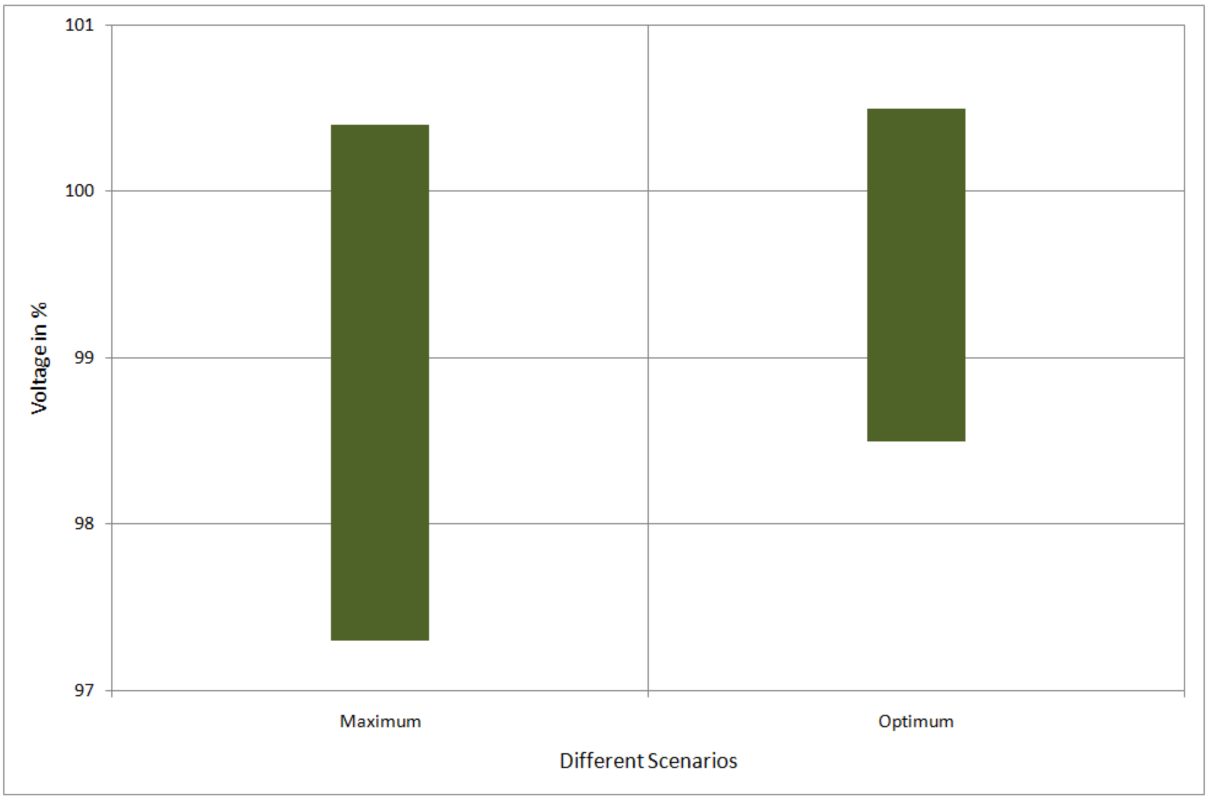

Figure 6 - 18: Voltage ranges all over the MV nodes for different scenarios

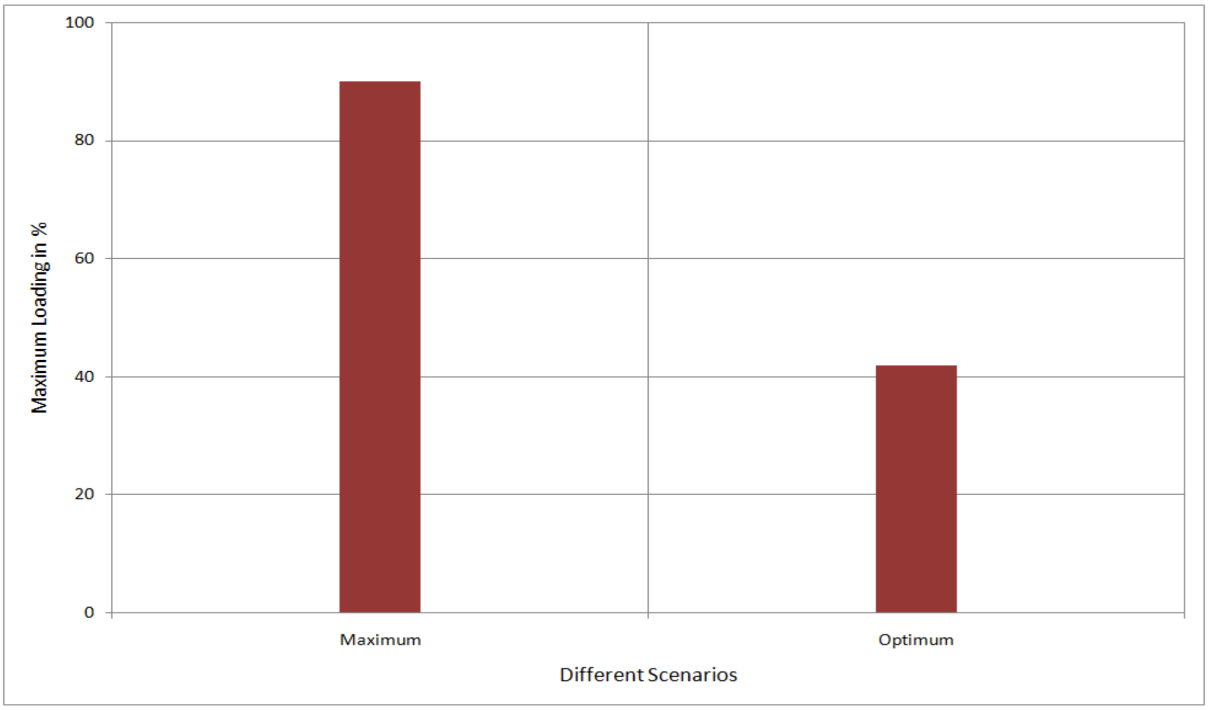

Figure 6 - 19: Maximum line loading for different scenarios

6.6.3 Hourly optimization scheme

Through the entire former presented scenario, the optimization was implemented to find the optimum switching state of the network through one day. In this phase the optimization was performed to find the optimal switching state for each one hour. Therefore, a comparison between the results can be made. Two days have been selected to conduct this implementation, Wi-Saturday-Rainy and Wi-Saturday-Sunny. The optimization has been conducted taking a time interval of 15 minutes for load flow with load profile. A summation of the energy losses before and after the optimization for each hour was computed and an average reduction has been evaluated. This average reduction is compared with the reduction which has been obtained by optimizing the switching states through the whole day one time; the two values are given in Fig. 6-20. It can be observed that there is no significant difference between a day-based optimization and an hour-based optimization. Therefore, it is better to switching only one time a day from the technical and economical point of views.

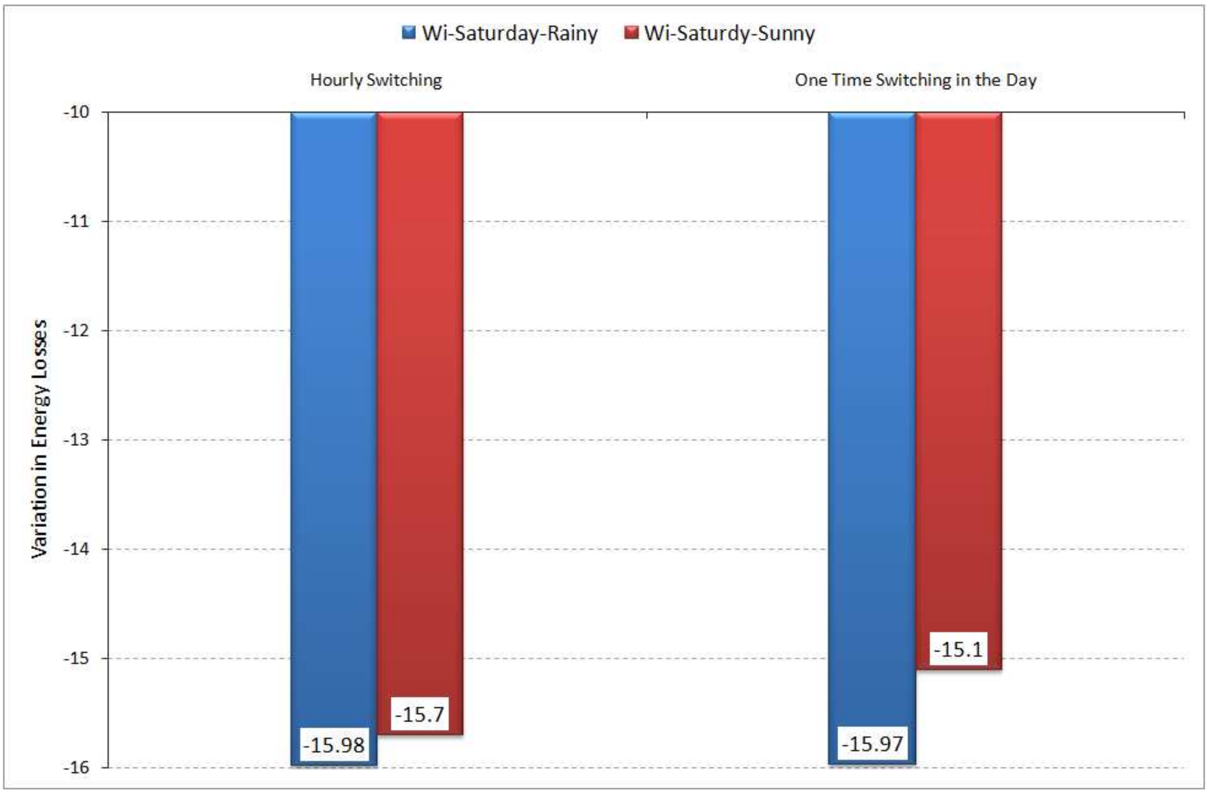

Figure 6 - 20: Variation in energy losses using different time based optimization

6.6 Summary

In this chapter a new methodology for optimizing the switching state of MV distribution networks with the existence of DG units is presented. The optimization algorithm is implemented to optimize the switching state of a typical network using different scenarios. In the first scenario, the load profiles have been used with a constant percentage of the rated power of each DG unit. In the second scenario the load and generation profiles are taken into consideration. The results of the proposed algorithm yields efficiency in minimizing the energy losses, improving the voltage through the network, and releasing the bottlenecks in the lines.

Distribution networks reconfiguration with the presence of high penetration level of DG power cannot only provide a chance for reducing the energy losses but also it can provide more opportunity for more integration of DG units. The presented algorithm can be implemented by the network operators based on forecasting the load and generation profiles. Moreover, it can also be implemented by mean of switching catalogue; this means that the optimization can be done for different day types with different generation. In this case and based on the forecasted data of the load and the generation the network operators can apply the optimal switching state for operation of their network with minimum energy losses.

CHAPTER 7: CONCLUSIONS AND FUTURE DIRECTIONS

7.1 Conclusions

The scope of the current study can be classified with this work related to the interconnection of DG units within the MV distribution networks. The growing interest all over the world in increasing the penetration levels of the DG units encourages the investigation of its related subjects. Therefore, an overview about the benefits and challenges arising from DG is essential. In this work, the following issues were investigated:

1. Evaluation of the impacts of DG on voltage stability and voltage limit loadability.
2. Efficient integration of the DG units for meeting the increased load demand.
3. Time series-based implications of the DWPG on a real MV distribution network.
4. Reconfiguration of the MV distribution networks with DG units.

7.1.1 Impacts of DG on voltage stability and voltage limit loadability of MV distribution networks

The influence of DG integration on the steady state voltage stability of MV distribution networks was assessed using a previously introduced voltage stability index. Applying different integration scenarios of DG units, it was found that the location of the DG unit has the main impact on the voltage stability more than the unit capacity. Moreover, dispersing of an amount of DG power, for the same feeder, is better than place it at a certain bus, with respect to the voltage stability, even if the dispersed power is lower than the concentrated one. This is considered as an important conclusion because in some cases the locations of the DG cannot be controlled (especially renewable energy based DG) and then this approach will be helpful for the enhancement of the voltage stability.

The loadability of MV distribution networks was tested according to two aspects. The first aspect is the voltage stability limit loadability (VSLL), while the second is the voltage limit loadability (VLL). The evaluation process was conducted based on continuation power flow (CPF) which is implemented in PSAT. The loadability aspects were tested on two different MV distribution networks by placing the DG units at each node of the network with different penetration levels and different reactive power injections. Moreover, the influences of supplying reactive power from the DG on the network losses have been studied. From the analysis, the following conclusions can be drawn:

- Integration of the DG into the distribution network enhances the loadability according to the two studied aspects.
- The VLL aspect shows better results than the VSLL aspect.

- At low penetration levels, changing the reactive power supplied from the DG unit has no significant impact on enhancing the VLL or VSLL aspects. While for the high PLs, this impact can be clearly observed.
- The optimal location to maximize the loadability, according to VLL aspect, depends on the variation of the penetration level.
- The reactive power should be controlled because it has significant impacts on the system losses.
- At each node of the network there is a certain capacity of the DG for minimizing the losses.
- Each distribution system should be studied in details using different analysis techniques when the DG is intended to be integrated.

7.1.2 Efficient integration of DG units for meeting the increased load demand

A new methodology for accommodating multi-DG units to MV distribution networks for enhancing the VLL was introduced. The suggested methodology was developed based on the CPF. The main idea behind this algorithm is identifying different nodes while dispersing a predefined DG power at these nodes. The proposed algorithm has the ability to identify some recommended nodes for connecting DG as a part of the solution for the increasing in the load demand. As an answer to the question which was highlighted as a motivation of this part of the work "can the DG units provide a part of the solution to face the increasing load demand?". It can be said yes the DG can provide a part of the solution of the dramatically load increase problem all over the world, if they are correctly located. The proposed method was implemented on a distribution network of 85 nodes. The results yield efficiency in increasing the amount of the load which can be supplied form the network while the voltages are kept within the limits. The conclusions which can be drawn are:

- Dispersing the same amount of the DG power at different nodes of the network enhances the VLL of the network more than concentrating this power at one node.
- More loads can be supplied with lower dispersed power of the DG when it compared with higher concentrated DG power.
- Dispersing the same power of the DG does not approximately affect the VSLL of the network when it compared with integration of the same DG power at the weakest node.
- The voltage profiles through the nodes are more uniform in the case of the dispersed DG power than those of the concentrated DG power.
- Integrating the DGs at the recommended nodes helps to get more decreasing of the active and reactive power losses.

7.1.3 Time series-based implications of DWPG on a real MV distribution network

A real MV distribution grid is analyzed with the existence of decentralized wind power generation (DWPG). The analysis was conducted based on time series of loads and wind power. The load is simulated using VDEW standard load profiles of the households which are connected at the LV side of each MV substation. Measured wind power data is implemented in the simulation. The availability to integrate a new wind generator into the network is also tested. From the analysis, the following conclusions can be figured out:

- Different planning aspects regarding the calculation of the maximum power for MV distribution networks are introduced.
- A new relation to calculate the maximum power based on measured data was presented.
- The maximum line loading is mainly increased in the area where the wind generators are connected especially if a large part of the generated power is not consumed in this area.
- As the wind generation units are connected in the same area and close to each other, it seems to be as a large unit so that its large effect is only on the voltages of the near areas.
- Feeders which connected in ring are less affected by the fluctuation in the wind power more than the feeders connected in radial.
- Despite that the existing wind generators are concentrated into area 3 and not dispersed the overall losses through the year increased by approximately ~197 MWh. That means it increases only by ~4.2 %. The reason behind that is the fluctuating nature of the wind power.

7.1.4 Reconfiguration MV distribution networks with DG units

Optimization of the switching state of a typical MV distribution network is presented in the current study. The MV network was optimized with the existence of different DG technologies. The Load profiles of households and commercials are used through the optimization process. The DG power has been simulated in two scenarios, constant power and generation with profile. The optimization algorithm is implemented using C++ with NEPLAN software. The proposed algorithm yields efficiency in minimizing the energy losses, improving the voltage through the network, and releasing the bottlenecks in the lines. From the analysis the following conclusions can be drawn:

- As the penetration of DG units increased the availability to minimize the energy losses through reconfiguration decreases.

- Optimization the switching state for the whole day one time may be better than trying to switch in an hourly scheme.

7.2 Future Directions

The current study represents a beginning attempt in addressing areas of challenges and benefits of utilizing the DG units into the future MV networks. Moving forward, some possible directions can be identified as follows:

- Investigating the impacts of power electronics converter based DG units on the dynamic voltage stability of distribution networks
- Evaluation of the transient stability of the distribution systems with the existence of power electronics converter based DG.
- Developing new algorithms for voltage and frequency control of converter based DG.
- Proposing different integration scenarios of DG into existing distribution networks according to the different operating constraints using load profiles into consideration.
- Developing new algorithms for reconfiguration of distribution networks combining the load and generation forecasting based on real system data.

REFERENCES

Abdelaziz, A. Y., Mohamed, F. M., Mekhamer, S. F., and Badr, M. A. L., 2010, "*Distribution system reconfiguration using a modified Tabu Search algorithm*," Electric power systems research, vol. 80, pp. 943-953.

Acharya, N., Mahat, P., and Mithulananthan, N., 2006, "*An analytical approach for DG allocation in primary distribution network*," International Journal of Electrical Power & Energy Systems, vol. 28, pp. 669-678.

Ackermann, T., Andersson, G., and Soeder, L., 2000, "*Distributed generation: a definition*," Electric Powe Systems Research, vol. 57, pp. 195 - 204.

Agalgaonkar, A. P., Kulkarni, S. V., and Khaparde, S. A., 2003, "*Impact of wind generation on losses and voltage profile in a distribution system*," in TENCON 2003, Conference on Convergent Technologies for Asia-Pacific Region, pp. 775-779.

Agustoni, A., Brenna, M., Faranda, R., Simioli, G., and Tironi, E., 2002, "*Distributed Generation Control Methodologies and Network Reconfiguration: Effects on Voltage Profile*," in Proceedings, Power System 2002 Conference: Impact of Distributed Generation, Clemson,Sc., Clemson, pp. 13-15.

Ajjarapu, V., 2006, *Computational techniques for voltage stability assessment and control*, 1st ed. New York: Springer.

Ajjarapu, V. and Christy, C., 1992, "*The continuation power flow: a tool for steady state voltage stability analysis*," IEEE Transactions on Power Systems, vol. 7, pp. 416-423.

Alonso, M. and Amaris, H., 2009, "*Voltage stability in distribution networks with DG*," in 2009 IEEE Bucharest Power Tech Conference, Bucharest, Romania, pp. 1-6.

Ault, G. and Cruden, A., 2000, "*Specification and testing of a comprehensive strategic analysis framework for distributed generation*," in Power Engineering Society Summer Meeting, 2000. IEEE, Seattle, WA , USA, pp. 1817-1822.

AWEA, 2005, "*American Wind Energy Association, Grid Code White Paper, Electrical Guide to Utility Scale Wind Turbines*," ed. Washington, DC.

Ayres, H. M., Silva, L. C. P. D., Freitas, W., de Almeida, M. C., and Costa, V. F. D., 2009, "*Evaluation of the impact of distributed generation on power losses by using a sensitivity-based method*," in 2009 IEEE Power & Energy Society General Meeting, Calgary, AB, pp. 1-6.

Azmy, A., 2005, "*Simulation and management of distributed generating units using intelligent techniques*," PhD PhD, Fachbereich Ingenieurwissenschaften, Universitat Duisburg-Essen, Duisburg.

Baran, M. E. and El-Markabi, I. M., 2007, "*A multiagent-based dispatching scheme for distributed generators for voltage support on distribution feeders*," IEEE Transactions on Power Systems,*,* vol. 22, pp. 52-59.

Beddoes, A., Lynch, C., Attree, M., and Marshall, M., 2007, "*The impact of distributed generation up on network losses*," in 19th International Conference on Electricity Distribution, CIRED 2007, Vienna, pp. 1-4.

Borges, C. and Falcao, D., 2006, "*Optimal distributed generation allocation for reliability, losses, and voltage improvement*," International Journal of Electrical Power & Energy Systems*,* vol. 28, pp. 413-420.

Bouffard, F. and Kirschen, D. S., 2008, "*Centralised and distributed electricity systems*," Energy Policy*,* vol. 36, pp. 4504-4508.

Broadwater, R. P., Khan, A. H., Shaalan, H. E., and Lee, R. E., 1993, "*Time varying load analysis to reduce distribution losses through reconfiguration*," IEEE Transactions on Power Delivery*,* vol. 8, pp. 294-300.

BWE Website, (2010), *Bundesverband Wind Energie e.V.* Available: http://www.wind-energie.de/en/

Calderaro, V., Milanovic, J., and Kayikci, M., 2009, "*The impact of distributed synchronous generators on quality of electricity supply and transient stability of real distribution network*," Electric Power Systems*,* vol. 79, pp. 134-143.

Calderaro, V., Piccolo, A., and Siano, P., 2006, "*Maximizing DG penetration in distribution networks by means of GA based reconfiguration*," in Future Power Systems, 2005 International Conference on, Amsterdam, pp. 1-6.

Casavola, A., Franzč, G., Menniti, D., and Sorrentino, N., 2011, "*Voltage regulation in distribution networks in the presence of distributed generation: A voltage set-point reconfiguration approach*," Electric power systems research*,* vol. 81, pp. 25-34.

Chakravorty, M. and Das, D., 2001, "*Voltage stability analysis of radial distribution networks* " International Journal of Electrical Power & Energy Systems*,* vol. 23, pp. 129-135

Chen, C. S. and Cho, M. Y., 1993, "*Energy loss reduction by critical switches*," Power Delivery, IEEE Transactions on*,* vol. 8, pp. 1246-1253.

Chen, H., Chen, J., Shi, D., and Duan, X., 2006, "*Power flow study and voltage stability analysis for distribution systems with distributed generation*," in IEEE Power Engineering Society General Meeting, 2006, Montreal (Quebec), Canada, pp. 1-8.

Chen, X., 2008, "*Effects of Distributed Generation on power loss, loadability and stability*," in IEEE SoutheastCon 2008, Huntsville, AL, pp. 468-473.

Chiradeja, P., 2005, "*Benefit of Distributed Generation: A Line Loss Reduction Analysis*," in 2005 IEEE/PES Transmission & Distribution Conference & Exposition: Asia and Pacific, Dalian, pp. 1-5.

Chiradeja, P. and Ramakumar, R., 2003, "*Voltage profile improvement with distributed wind turbine generation-a case study*," in 2003 IEEE Power Engineering Society General Meeting, pp. 2331-2336.

Choi, J.-h., Ieee, S. M., Kim, J.-c., and Ieee, M., 2000a, "*Network reconfiguration at the power distribution system with dispersed generations for loss reduction*," in 2000 IEEE Power Engineering Society Winter Meeting, pp. 2363-2367.

C**hoi, J.-H. and Kim, J.-C., 2000b,** "Network Reconfiguration at the Power Distribution System with Dispersed Generations for Loss Reduction," in *Conference proceedings, 2000 IEEE Power Engineering Society winter meeting*, ed Piscataway, NJ: IEEE Servie Center, pp. 2363-2367.

CIRED, 1999, "*Dispersed Generation Preliminary Report for Discussion of CIRED* " CIRED, Working Group WG04, Nice

Cohen, J. M. and Wind, T. A., 2001, "*Distributed Wind Power Assessment*," National Wind Coordinating Committee,

D.Little, A., 2000, "*Reliability and Distributed Generation*," ed, pp. 1-44.

Dai, C. and Baghzouz, Y., 2004, "*On the voltage profile of distribution feeders with distributed generation*," in IEEE Power Engineering Society General Meeting, 2003,, pp. 1136-1140.

Das, D., 2006, "*A Fuzzy Multiobjective Approach for Network Reconfiguration of Distribution Systems*," IEEE Transactions on Power Delivery*,* vol. 21, pp. 202-209.

Das, D., Kothari, D. P., and Kalam, A., 1995, "*Simple and efficient method for load flow solution of radial distribution networks* " International Journal of Electrical Power & Energy Systems*,* vol. 17, pp. 335-346

Deng, W., Pei, W., and Qi, Z., 2008, "*Impact and improvement of Distributed Generation on voltage quality in Micro-grid*," in 2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, Nanjuing, pp. 1737-1741.

DG Website, (2010), *Distributed Generation*. Available: http://www.distributed-generation.com/applications.htm

DGEM Website, (2010), *Distributed Generation Education Modules*. Available: http://www.dg.history.vt.edu/ch1/introduction.html

Duan, J., Yang, X., and Yang, W., 2009, "*Study on Power Flow Calculation and Voltage Profile in Distribution System with Distributed Generation*," in 2009 Asia-Pacific Power and Energy Engineering Conference, Wuhan, pp. 1-4.

Dugan, R. C., 2003, *Electrical power systems quality*, 2nd ed. New York: McGraw-Hill.

Dyussembekova, N., Kurrat, M., and Waitschat, H., 2008, "*Untersuchung der Lastprofile von Niederspannungsnetzbezirken*," in 2008 X. Symposium Energieinnovation, TU Graz, Österreich., pp. 1-12.

e.on Avacon, 2007, "*Verfahrensanweisung Planung MS-/NS-Netze*," E.on

El-Khattam, W. and Salama, M. M. A., 2004, "*Distributed generation technologies, definitions and benefits*," Electric power systems research*,* vol. 71, pp. 119-128.

El-Sadek, M. Z., 2002, *Power System Voltage Stability and Power Quliaty*. Assuit, Egypt: Mukhtar Press.

En BS, (2008), *Braunschweiger Netz GmbH*. Available: http://www.bs-netz.de/

Foote, C., 2000, "*Future Directions for Distribution Networks*," ed. Glasgow, p. 39.

Forsyth, T. and Baring-Gould, I., 2007, "*Distributed Wind Market Applications* " National Renewable Energy Laboratory

Fudou, H., Genji, T., and Nakanishi, Y. F. Y., 1997, "*A genetic algorithm for network reconfiguration using three phase unbalanced load flow*," in ISAP'97 Intelligent Systems Applications to Power Systems, Seoul, Korea, pp. 1-5.

Golshan , M. E. H. and Arefifar, S. A., 2006, "*Distributed generation , reactive sources and network-configuration planning for power and energy-loss reduction*," IET Generation, Transmission & Distribution*,* vol. 153, pp. 127-136.

Gomes, F. V.*, et al.*, 2005, "*A new heuristic reconfiguration algorithm for large distribution systems*," IEEE Transactions on Power Systems,*,* vol. 20, pp. 1373-1378.

González-Longatt, F., 2007, "*Impact of Distributed Generation over Power Losses on Distribution System*," in 9th International Conference on Electrical Power and Utilization, Barcelona, Spain, pp. 1-6.

Gözel, T. and Hocaoglu, M. H., 2009, "*An analytical method for the sizing and siting of distributed generators in radial systems*," Electric power systems research*,* vol. 79, pp. 912-918.

Greene, N. and Hammerschlag, R., 2000, "*Small and Clean Is Beautiful:: Exploring the Emissions of Distributed Generation and Pollution Prevention Policies*," The Electricity Journal*,* vol. 13, pp. 50-60.

Griffin, T., Tomsovic, K., Secrest, D., and Law, A., 2002, "*Placement of dispersed generation systems for reduced losses*," in Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, pp. 1-9.

Guimaraes, M. A. N. and Castro, C. A., 2005, "*Reconfiguration of Distribution Systems for Loss Reduction Using Tabu Search*," in IEEE Power System Computation Conference (PSCC 2005), pp. 1-6.

Haque, M. H., 1995, "*A Fast method for Determining the Voltage Stability Limit of a Power System*," Electric Powe Systems Research, vol. 32, pp. 35-43.

Harrison, G. P., Piccolo, A., Siano, P., and Wallace, A. R., 2007, "*Distributed Generation Capacity Evaluation Using Combined Genetic Algorithm and OPF*," International Journal of Emerging Electric Power Systems, vol. 8, p. Article 7.

Hayashi, Y., Takano, H., and Matsuki, J., 2006, "*Integrated method of determining transmission and distribution loss-minimum network configurations*," IEEJ Transactions on Electrical and Electronic Engineering, vol. 1, pp. 216-225.

Hedayati, H., Nabaviniaki, S. A., and Akbarimajd, a., 2008, "*A Method for Placement of DG Units in Distribution Networks*," IEEE Transactions on Power Delivery, vol. 23, pp. 1620-1628.

Hedayati, H., Nabaviniaki, S. A., and Akbarimajd, A., 2006, "*A New Method for Placement of DG Units in Distribution Networks*," 2006 IEEE PES Power Systems Conference and Exposition, pp. 1904-1909.

Hemdan, N. G. A. and Kurrat, M., 2009, "*Loadability Aspects for Medium Voltage Distribution Networks with Integration of Decentralized Generation*," International Journal of Distributed Energy Resources, vol. 5, pp. 187-200.

Herman, L., Blazic, B., and Papic, I., 2009, "*Voltage profile support in LV distribution networks with distributed generation*," in 2009 Proceedings of the 44th International Universities Power Engineering Conference (UPEC), pp. 1-5.

Honton, E., 2000, "*Increasing power reliability via distributed generation*," ed: Resource Dynamics Corporation, pp. 1-20.

Huang, G. and Zhao, L., 2001, "*Measurement based voltage stability monitoring of power system*," ed: Power Systems Engineering Research Center, University of Wisconsin, Madison,WI,.

IEA, 2005, "*World Energy Outlook 2005*,"

IEEE, 2003, "*1547 IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*," in *Standard Coordinating Committee 21*, ed: IEEE.

Jaganathan, R. and Saha, T., 2004, "*Voltage stability analysis of grid connected embedded generators*," in Australasian Universities Power Engineering Conference, Brisbane, Australia, pp. 1-6.

Jasmon, G. B. and Lee, L. H. C. C., 1993, "*New contingency ranking technique incorporating a voltage stability criterion*," IEE Proceedings C Generation, Transmission and Distribution, vol. 140, pp. 87-90.

Jaswanti and Thakur, T., 2007, "*A New Heuristic Network Reconfiguration Algorithm for Radial Distribution System*," in Proceedings of the 9th International Conference on Electric Power Quality and Utilisation, Barcelona, Spain, pp. 1-6.

Jenkins, N. and Strbac, G., 1997, "*Impact of embedded generation on distribution system voltage stability*," in IEE Colloquium onVoltage Collapse (Digest No: 1997/101), London, pp. 1-4.

Jithendra Gowd, K., Sai Babu, C., and Siranagaraju, S., 2008, "*Impact of Distributed Generators on Power Loss in Distribution System*," Journal of Engineering and Applied Science, vol. 3, pp. 31-37.

Joos, G., Ooi, B. T., McGillis, D., Galiana, F. D., and Marceau, R., 2000, "*The potential of distributed generation to provide ancillary services*," in 2000 Power Engineering Society Summer Meeting (Cat. No.00CH37134), Seattle, WA , USA, pp. 1762-1767.

Kaufmann, W., 1995, *Planung öffentlicher Elektrizitätsverteilungs-Systeme*: VDE-Verlag GMBH.

Keane, A. and O'Malley, M., 2006, "*Impact of Distributed Generation Capacity on Losses*," presented at the IEEE Power Engineering Society General Meeting, Montreal, Que. .

Khan, H. and Choudhry, M. A., 2010, "*Implementation of Distributed Generation (IDG) algorithm for performance enhancement of distribution feeder under extreme load growth*," International Journal of Electrical Power & Energy Systems, vol. 32, pp. 985-997.

Khushalani, S., 2006, "*Development of power flow with distributed generators and reconfiguration for restoration of unbalanced distribution systems*," PhD PhD, Department of Electrical and Computer Engineering, Mississippi State University, Mississippi, Mississippi State.

Koeppel, G., 2003, "*Distributed Generation—Literature Review and Outline of the Swiss Situation*," in *Systems Laboratory. ETH Swiss Federal Institute of*, ed.

Konstantinos, A., 2004, "*Integration of distributed generation in low voltage Networks: power quality and economics*," M.Sc. M.Sc., University of Strathclyde Glasgow, United Kingdom.

Korpås, M., 2004, "*Distributed energy systems with wind power and energy storage*," PhD PhD, Department of Electrical Power Engineering, Norwegian University of Science and Technology, Faculty of Information Technology, Mathematics and Electrical Engineering, Trondheim.

Latheef, A., Negnevitsky, M., Muttaqi, K., and Perera, S., 2008, "*Present understanding of the impact of Distributed Generation on Power Quality*," in Power Engineering Conference, 2008. AUPEC'08. Australasian Universities, pp. 1-6.

Lee, K. Y. and El-Sharkawi, M. A., 2008, *Modern heuristic optimization techniques : theory and applications to power systems*. Piscataway, N.J. Hoboken, N.J.: IEEE Press ; Wiley-Interscience.

Li, S., Tomsovic, K., and Hiyama, T., 2000, "*Load following functions using distributed energy resources*," in IEEE 2000 Power Engineering Society Summer Meeting, Seattle, WA , USA, pp. 1756-1761.

Loevenbruck, P. and Sacre, A., 2009, "*Impact of distributed generation on losses, draw off costs from transmission network and investments of the french distribution network operator ERDF*," in CIRED 2009. 20th International Conference on Electricity Distribution, Prague, pp. 1-4.

Lomi, A., Hien, N. C., and Mithulananthan, N., 2009, "*Application of distributed generation to enhance loadability of distribution system, a case study*," in 2009 IEEE PES/IAS Conference onSustainable Alternative Energy (SAE), Valencia pp. 1-7.

Lopez, E., Opazo, H., Garcia, L., and Bastard, P., 2004, "*Online reconfiguration considering variability demand: applications to real networks*," IEEE Transactions on Power Systems,Power Systems, vol. 19, pp. 549-553.

Lund, P., Mogstad, O., Neimane, V., and Heieren, A., 2003, "*Connection of distributed generation – effect on the power system*," SINTEF Energy Research, Trondheim, Norway

Maki, K., 2004, "*Effect of wind power based distributed generation on protection of distribution network*," in Eighth IEE International Conference on Developments in Power System Protection, Amsterdam, Netherlands, pp. 327-330.

Mariotto, L., Pinheiro, H., Cardoso, G., and Muraro, M., 2007a, "*Determination of the Static Voltage Stability Region of Distribution Systems with the Presence of Wind Power Generation*," in Clean Electrical Power, 2007. ICCEP'07. International Conference on, Capr, italy, pp. 556-562.

Mariotto, L., Pinheiro, H., Junior, G. C., Muraro, M. R., and Jaskulski, I. W., 2007b, "*Determination of the impact of wind power generation on the steady state voltage stability of distribution systems*," in 9th Brazilian Power Electronics Conference, Blumenau, Brazil, pp. 602-607.

Masters, C., 2002, "*Voltage rise: the big issue when connecting embedded generation to long 11 kV overhead lines*," Power Engineering Journal, vol. 16, pp. 5-12.

Masters, G. M., 2004, *Renewable and efficient electric power systems*. Hoboken, NJ: John Wiley & Sons.

Meier, H., Fünfgeld, C., Adam, T., and Schieferdecker, B., 1999, "*Repräsentativen VDEW-Lastprofile, WDEW Materialien M-28/29*," Brandenburgische Technische Universität Cottbus, Lehrsthul Energiewirtschaft, Frankfurt (Main)

Mekhamer, S. F., Abdelaziz, A. Y., Mohammed, F. M., and Badr, M. A. L., 2008, "*A new intelligent optimization technique for distribution systems reconfiguration*," 12th International Middle-East Power System Conference, MEPCON 2008, pp. 397-401.

Meyers, E. M. and Hu, M. G., 2001, "*Clean Distributed Generation: Policy Options to Promote Clean Air and Reliability*," The Electricity Journal, vol. 14, pp. 89-98.

Milano, F., 2007, "*Documentation for PSAT version 2.0.0, ,*"

Milano, F., 2005, "*An open source power system analysis toolbox*," IEEE Transactions on Power Systems, vol. 20, pp. 1199-1206.

Mishima, Y., 2005, "*Method for Minimum-Loss Reconfiguration of Distribution System by Tabu Search*," Electrical Engineering in Japan, vol. 152, pp. 18-25.

Mishima, Y., Nara, K., Satoh, T., Ito, T., and Kaneda, H., 2005, "*Method for Minimum-Loss Reconfiguration of Distribution System by Tabu Search*," Electrical Engineering in Japan, vol. 152, pp. 18-25.

Mithulananthan, N. and Oo, T., 2006, "*Distributed generator placement to maximize the loadability of a distribution system*," International Journal of Electrical Engineering Education, vol. 43, pp. 107-118.

MOEE Website, (2010), *Annual Report 2008/2009*. Available: http://www.moee.gov.eg/English/Electric%20eng%202010.pdf

Moghavvemi, M. and Faruque, M. O., 2002, "*Technique for assessment of voltage stability in ill-conditioned radial distribution network*," IEEE Power Engineering Review,, vol. 21, pp. 58-60.

Morsi, W. G. and El-Hawary, M. E., 2008, "*Effect of distributed generation on voltage flicker in distributed systems: A case study*," in 2008 Canadian Conference on Electrical and Computer Engineering, Niagara Falls, ON, pp. 000065-000070.

Mount, E., 2003, *Distributed Generation; The Power Paradigm for the New Millennium (Book)* vol. 57.

Nakawiro, W. and Erlich, I., 2008, "*Online voltage stability monitoring using Artificial Neural Network*," in 2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, Nanjuing, pp. 941-947.

Nazari, M. and Parniani, M., 2006, "*Determining and Optimizing Power Loss Reduction in Distribution Feeders due to Distributed Generation*," in Power Systems Conference and Exposition, 2006. PSCE '06. 2006 IEEE PES, Atlanta, GA , USA, pp. 1914 - 1918.

Nuroglu, F. M. and Arsoy, A. B., 2008, "*Voltage profile and short circuit analysis in distribution systems with DG*," in 2008 IEEE Canada Electric Power Conference, Vancouver, BC, pp. 1-5.

NYSERDA Website, *New York State Energy Research and Development Authority*. Available: http://chp.nyserda.org/support/terms.cfm

Ochoa, L. F., Padilha-Feltrin, A., and Harrison, G. P., 2007, "*Maximizing the accommodation of distributed wind power generation*," in 19th International Conferance on Electricity Distribution, CIRED 2007, Vienna, pp. 1-4.

Ochoa, L. F., Padilha-Feltrin, A., and Harrison, G. P., 2008, "*Time-series-based maximization of distributed wind power generation integration*," Energy Conversion, IEEE Transactions on, vol. 23, pp. 968-974.

Oliveira, M. E., Ochoa, L. F., Padilha-Feltrin, A., and Mantovani, J. R. S., 2004, "*Network reconfiguration and loss allocation for distribution systems with distributed generation*," in 2004 IEEE/PES Transmision and Distribution Conference and Exposition: Latin America, pp. 206-211.

OOCC Website, (2010), *Office of the Ohio Consumers' Counsel*. Available: http://www.pickocc.org/publications/electric/Understanding_Distributed_Generation.pdf

Papazoglou, T. and Gigandidou, A., 2003, "*Impact and benefits of distributed wind generation on quality and security in the case of the Cretan EPS*," in CIGRE/IEEE PES International Symposium on Quality and Security of Electric Power Delivery Systems,, pp. 193-197.

Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., and D, W., 2005, "*Distributed generation : definition , benefits and issues*," Energy Policy, vol. 33, pp. 787-798.

Petrie, E. M., Willis, H. L., and Takahashi, M., 2001, "*Distributed generation in developing countries*," vol. 2, ed, p. 5.

Pielke, M. and Kurrat, M., 2007, "*Integration of combined heat and power micro units into the low voltage network by using a grid oriented operation mode*," in 2nd General Assembly of the European Technology Platform SmartGrids, Bad Staffelstein.

Pielke, M. and Kurrat, M., 2008, "*Potentials for asset optimizations in low and medium voltage networks through grid oriented feeding of distributed generation*," in Transmission and Distribution Conference and Exposition, 2008. IEEE/PES, Chicago, IL, pp. 1-7.

Quezada, V. H. M., Abbad, J. R., and Roman, T., 2006, "*Assessment of energy distribution losses for increasing penetration of distributed generation*," IEEE Transactions on Power Systems, vol. 21, pp. 533-540.

Raju, G. and Bijwe, P., 2008, "*An efficient algorithm for minimum loss reconfiguration of distribution system based on sensitivity and heuristics*," IEEE Transactions on Power Systems, vol. 23, pp. 1280-1287.

Ramesh, L., Chowdhury, S. P., Chowdhury, S., Song, Y. H., and Natarajan, A. A., 2008, "*Voltage stability analysis and real power loss reduction in distributed distribution system*," in 2008 IEEE/PES Transmission and Distribution Conference and Exposition, Powering toward the Future, Chicago, pp. 1-6.

RDC, R. D. C., 2001, "*Assessment of Distributed Generation Technology Applications*," in *Power*, ed. Vienna, p. 32.

Repo, S. and Laaksonen, H., 2003, "*A case study of a voltage rise problem due to a large amount of distributed generation on a weak distribution network*," in 2003 IEEE Bologna Power Tech Conference Proceedings, Bologna, pp. 1-6.

Rugthaicharoencheep, N. and Sirisumrannukul, S., 2009a, "*Feeder Reconfiguration for Loss Reduction in Distribution System with Distributed Generators by Tabu Search*," GMSARN International Journal, vol. 3, pp. 47-54.

Rugthaicharoencheep, N. and Sirisumrannukul, S., 2009b, "*Feeder Reconfiguration with Dispatchable Distributed Generators in Distribution System by Tabu Search*," in Proceedings of the 44th International Universities Power Engineering Conference (UPEC), 2009, Glasgow, pp. 1-5.

Sahoo, N. C., Ranjan, R., Prasad, K., and Chaturvedi, a., 2007, "*A fuzzy-tuned genetic algorithm for optimal reconfigurations of radial distribution network*," European Transactions on Electrical Power, vol. 17, pp. 97-111.

Salman, S. K., 1996, "*The Impcat of Embedded Generation on Voltage Regulation and Losses of Distribution Networks* " in IEE Colloquium on the Impcat of Embedded Generation on Distribution Networks pp. 1-5.

Sarfi, R. J., Salama, M., and Chikhani, A., 1994, "*A survey of the state of the art in distribution system reconfiguration for system loss reduction*," Electric power systems research, vol. 31, pp. 61-70.

Sarfi, R. J., Salama, M. M. a., and Chikhani, a. Y., 1996, "*Distribution system reconfiguration for loss reduction: an algorithm based on network partitioning theory*," IEEE Transactions on Power Systems, vol. 11, pp. 504-510.

Schulz, C. and Kurrat, M., 2006, "*Business models for distributed power generation with combined heat and power micro-units*," The 3rd International Conference - European Electricity Market,EEM06, pp. 1-8.

Shin, B. C. G., 1994, "*Development of the loss minimization function for real time power system operations: a new tool*," IEEE Transactions on Power Systems, vol. 9, pp. 2028-2034.

Smart, P., Dinning, A., Maloyd, A., Causebrook, A., and Cowdroy, S., 2006, "*Accommodating Distributed Generation, Econnect Project No:1672*," ed. London, p. 91.

Subburaj, P., Ramar, K., Ganesan, L., and Venkatesh, P., 2006, "*Distriution system reconfiguration for loss reduction using genetic algorithm*," Journal of Electrical Systems, vol. 2, pp. 198-207.

Sun, Q., Li, Z., and Zhang, H., 2009, "*Impact of Distributed Generation on Voltage Profile in Distribution System*," in 2009 International Joint Conference on Computational Sciences and Optimization, Sanya; Hainan; China, pp. 249-252.

Thong, V. V. and Belmans, R., 2004a, "*Dispersed Generation Interconnection and Its Impact on Power Loss and Protection System*," in IEEE Young Researchers Symposium in Electrical Power Engineering - Intelligent Energy Conversion, Delft, pp. 1-6.

Thong, V. V. and Belmans, R., 2006, "*Distributed Generation Overview: Current Status and Challenges*," International Review of Electrical Engineering, vol. 1, pp. 178-189.

Thong, V. V., Dommelen, D. V., Driesen, J., and Belmans, R., 2004b, "*Impact of large scale distributed and unpredictable generation on voltage and angle stability of transmission system*," in Cigré session,, Paris, pp. 1-8.

Thong, V. V., Driesen, J., and Belmans, R., 2004c, "*Impact of large scale distributed and unpredictable generation on voltage and angle stability of transmission system*," presented at the Cigre session.

Thong, V. V., Driesen, J., and Belmans, R., 2003a, "*Impacts of embedded generation on voltage stability of distribution system*," in Universities Power Engineering Conference, Greece, pp. 1-4.

Thong, V. V., Driesen, J., and Belmans, R., 2003b, "*Improving voltage stability with the connection of distributed generation*," in European Power and Energy Systems, EuroPES, Marbella, Spain, pp. 1-5.

Thong, V. V., Driesen, J., and Belmans, R., 2005, "*Power quality and voltage stability of distribution system with distributed energy resources*," International Journal of Distributed Energy Reasources, vol. 1, pp. 227-240.

Thong, V. V., Driesen, J., and Belmans, R., 2007, "*using distributed generation to support and provide ancillary services for the power system*," presented at the International Conference on Clean Electrical Power, Renewable Energy Resources Impact, ICCEP'07 Capri, Italy.

Trieb, F. and Steinhagen, H. M., 2007, "*Europe – Middel East – North Africa coopertion for sustainable electricity and water*," Sustainable Science Journal, vol. 2, pp. 205-219.

VDE, 2008, "*conditions for connection to the medium-voltage network*," in *Technische Anschlussbedingungen für den Anschluss an das Mittelspannungsnetz* vol. TAB Mittelspannung 2008, ed.

VDI, 2007, "*Referenzlastprofile von Ein-und Mehrfamilienhäusern für den Einsatz von KWK Anlagen, VDI Richtlinien, VDI 4655*," ed: VDI.

Viawan, F. A. and Karlsson, D., 2008, "*Voltage and reactive power control in systems with synchronous machine-based distributed generation*," IEEE Transactions onPower Delivery, vol. 23, pp. 1079-1087.

Völler, S., Al-Awaad, A. R., and Verstege, J. F., 2009, "*Wind farms with energy storages integrated at the control power market*," in 2009 CIGRE-IEEE PES Symposium, Integration of Wide-Scale Renewable Resources into the Power Delivery System, pp. 1-13.

Wagner, T., Chikhani, A., and Hackam, R., 1991, "*Feeder reconfiguration for loss reduction: an application of distribution automation*," IEEE Transactions on Power Delivery, vol. 6, pp. 1922-1933.

Wang, C. and Nehrir, M. H., 2004, "*Analytical Approaches for Optimal Placement of Distributed Generation Sources in Power Systems*," IEEE Transactions on Power Systems, vol. 19, pp. 2068-2076.

Wang, S., 2009, "*Distributed generation and its effect on distribution network system*," in 20th International Conference on Electricity Distribution, CIRED 2009, Prague, pp. 1-4.

Weber, H. and Kleimaier, M., 2009, "*Grid Integration of Wind Generation*," presented at the 2009 CIGRE/IEEE PES Joint Symposium, Integration of Wide-Scale Renewable Resources Into the Power Delivery System, Calgary

Wind, T. A. and Coil, A. T., 2005, "*Distributed Wind Generation Study For Northeast Colorado*," Wind Utility Consulting, Colorado

Winter, W., Haslaner, T., and Obernberger, I., 2001, "*Untersuchungen der Gleichzeitigkeit in kleinen und mittleren Nahwärmenetzen*," presented at the Euroheat & Power, 09/10/2001.

WKO Website, (2009), *Standardisierte Lastprofile*. Available: http://portal.wko.at/wk/dok_detail_file.wk?AngID=1&DocID=603304&StID=289986

Xiong, N., Cheng, H., Yao, L., and Bazargan, M., 2008, "*Switch group based Tabu search algorithm for distribution network reconfiguration*," 2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, pp. 820-822.

Xu, X., Wang, C., and Feng, X., 2009, "*A Tabu Search Approach for Distribution Network Reconfiguration Based on GIS*," 2009 International Workshop on Intelligent Systems and Applications, pp. 1-4.

Yehia, M. A., Matar, E. E., Hobeila, N. Y., and Avedikian, A. D., 2002, "*A heuristic algorithm for electric distribution networks optimal feeder configuration using geographic information system*," IEEE Transactions on Power Systems,, vol. 17, pp. 1232-1237.

Zareipour, H., Bhattacharya, K., and Canizares, C. A., 2004, "*Distributed generation: Current status and challenges*," in 36th Annual North American Conferance, pp. 1-8.

Zeng, M., Wu, J., Wang, J., and Tian, K., 2010, "*Impact of Intermittent Wind Distributed Generation on the Reliability of Distribution System*," in 2010 Asia-Pacific Power and Energy Engineering Conference, Chengdu, pp. 1-6.

Zhang, D., Fu, Z., and Zhang, L., 2007, "*An improved TS algorithm for loss-minimum reconfiguration in large-scale distribution systems*," Electric power systems research, vol. 77, pp. 685-694.

APPENDIX A

A.1 Data for 69-Node Distribution Network

Table A - 1: Line and load data of 69-node distribution network [Das,2006]

Line Number	Sending Node (IS)	Receiving Node (IR)	R (Ω)	X (Ω)	P(IR) kW	Q(IR) kVAr
1	1	2	1.097	1.074	100	90
2	2	3	1.463	1.432	60	40
3	3	4	0.731	0.716	150	130
4	4	5	0.366	0.358	75	50
5	5	6	1.828	1.790	15	19
6	6	7	1.097	1.074	18	14
7	7	8	0.731	0.716	13	10
8	8	9	0.731	0.716	16	11
9	4	10	1.080	0.734	20	10
10	10	11	1.620	1.101	16	9
11	11	12	1.080	0.734	50	40
12	12	13	1.350	0.917	105	90
13	13	14	0.810	0.550	25	15
14	14	15	1.944	1.321	40	25
15	7	68	1.080	0.734	100	60
16	68	69	1.620	1.101	40	30
17	1	16	1.097	1.074	60	30
18	16	17	0.366	0.358	40	25
19	17	18	1.463	1.432	15	9
20	18	19	0.914	0.895	13	7
21	19	20	0.804	0.787	30	20
22	20	21	1.133	1.110	90	50
23	21	22	0.475	0.465	50	50
24	17	23	2.214	1.505	60	40
25	23	24	1.620	1.110	100	80
26	24	25	1.080	0.734	80	65
27	25	26	0.540	0.367	100	60
28	26	27	0.540	0.367	100	55
29	27	28	1.080	0.734	120	70
30	28	29	1.080	0.734	105	70
31	20	30	0.366	0.358	80	50
32	30	31	0.731	0.716	60	40
33	31	32	0.731	0.716	13	8
34	32	33	0.804	0.787	16	9
35	33	34	1.170	1.145	50	30
36	34	35	0.768	0.752	40	28
37	35	36	0.731	0.716	60	40
38	36	37	1.097	1.074	40	30
39	37	38	1.463	1.432	30	25
40	32	39	1.080	0.734	150	100
41	39	40	0.540	0.367	60	35
42	40	41	1.080	0.734	120	70
43	41	42	1.836	1.248	90	60

Table A-1: Continued

Line Number	Sending Node (IS)	Receiving Node (IR)	R (Ω)	X (Ω)	P(IR) kW	Q(IR) kVAr
44	42	43	1.296	0.881	18	10
45	40	44	1.188	0.807	16	10
46	44	45	0.540	0.367	100	50
47	42	46	1.080	0.734	60	40
48	35	47	0.540	0.367	90	70
49	47	48	1.080	0.734	85	55
50	48	49	1.080	0.734	100	70
51	49	50	1.080	0.734	140	90
52	70	51	0.366	0.358	60	40
53	51	52	1.463	1.432	20	11
54	52	53	1.463	1.432	40	30
55	53	54	0.914	0.895	36	24
56	54	55	1.097	1.074	30	20
57	55	56	1.097	1.074	43	30
58	52	57	0.270	0.183	80	50
59	57	58	0.270	0.183	240	120
60	58	59	0.810	0.550	125	110
61	59	60	1.296	0.881	25	10
62	55	61	1.188	0.807	10	5
63	61	62	1.188	0.807	150	130
64	62	63	0.810	0.550	50	30
65	63	64	1.620	1.101	30	20
66	62	65	1.080	0.734	130	120
67	65	66	0.540	0.367	150	130
68	66	67	1.080	0.734	25	15

A.2 Data for 15-Node Distribution Network (1st Case Study)

Table A - 2: Line and load data of 15-node distribution network [Das et al.,1995]

Line Number	Sending Node (IS)	Receiving Node (IR)	R (Ω)	X (Ω)	S(IR) kVA
1	1	2	1.35309	1.32349	63
2	2	3	1.17024	1.14464	100
3	3	4	0.84111	0.82271	200
4	4	5	1.52348	1.02760	63
5	2	9	2.01317	1.35790	100
6	9	10	1.68671	1.13770	63
7	2	6	2.55727	1.72490	200
8	6	7	1.08820	0.73400	200
9	6	8	1.25143	0.84410	100
10	3	11	1.79553	1.21110	200
11	11	12	2.44845	1.65150	100
12	12	13	2.01317	1.35790	63
13	4	14	2.23081	1.50470	100
14	4	15	1.19702	0.80740	200

Power factor of all loads is taken equal to 0.7 lagging

A.3 Data for 15-Node Distribution Network (2nd Case Study)

Table A - 3: Line and load data of 15-node distribution network [Li et al.,2000]

Line Number	Sending Node (IS)	Receiving Node (IR)	R (P.U.)	X (P.U.)	P(IR) P.U.	Q(IR) P.U.
1	1	2	0.003145	0.075207	0.0208	0.0021
2	2	3	0.00033	0.001849	0.0495	0.0051
3	3	4	0.006667	0.030808	0.0958	0.0098
4	3	12	0.027502	0.127043	0.0132	0.0014
5	4	5	0.005785	0.014949	0.0442	0.0045
6	4	7	0.008001	0.036961	0.0638	0.0066
7	5	6	0.014141	0.036547	0.0113	0.0012
8	7	8	0.008999	0.041575	0.0323	0.0033
9	8	9	0.00700	0.032346	0.0213	0.0022
10	9	10	0.003666	0.01694	0.0208	0.0029
11	10	11	0.008999	0.041575	0.2170	0.2200
12	12	13	0.031497	0.081405	0.0029	0.0003
13	13	14	0.039653	0.102984	0.0161	0.0016
14	14	15	0.01607	0.004153	0.0139	0.0014

Base voltage = 6.6 kV, Base MVA = 10 MVA

APPENDIX B

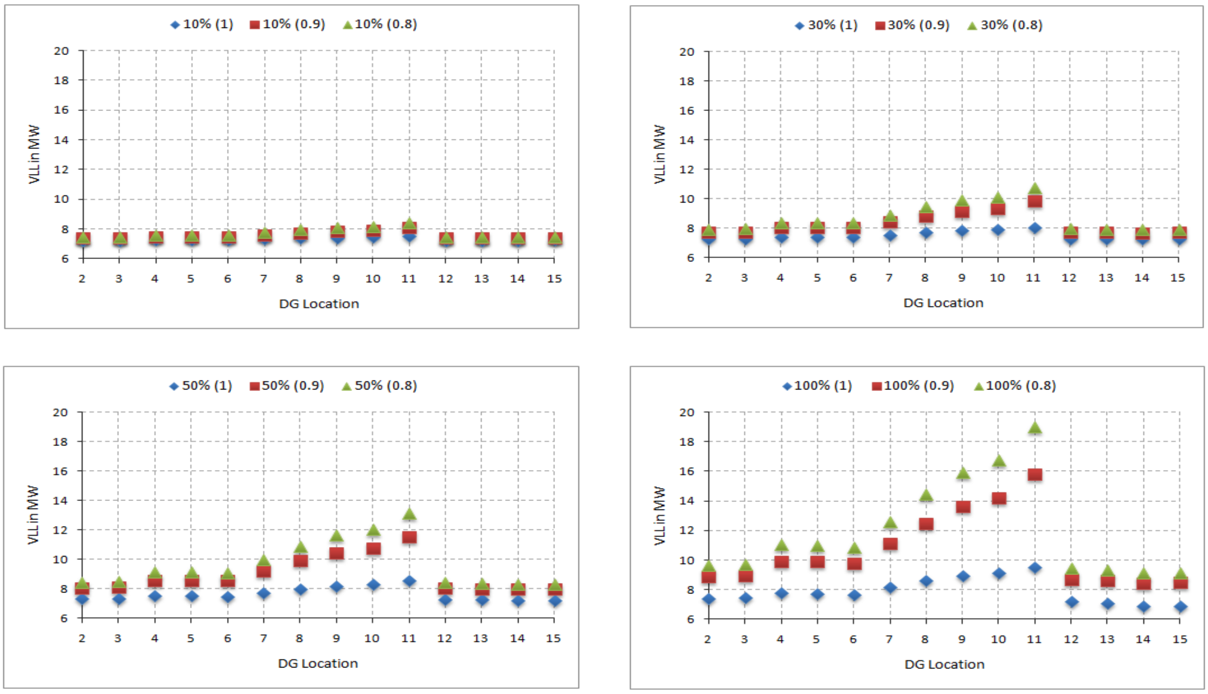

Figure B - 1 Maximum loading according to the voltage limit loadability for the 1st case study

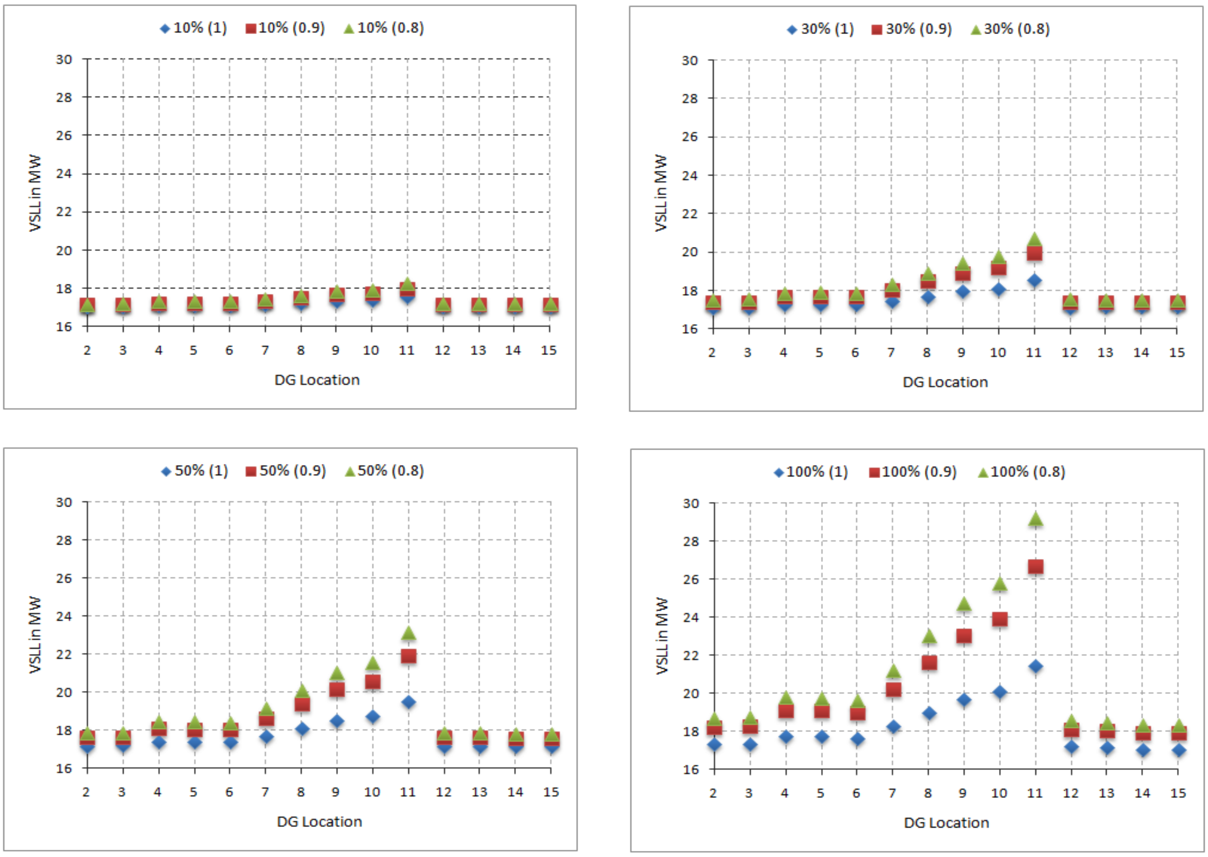

Figure B - 2: Maximum loading according to the voltage limit loadability for the 1st case study

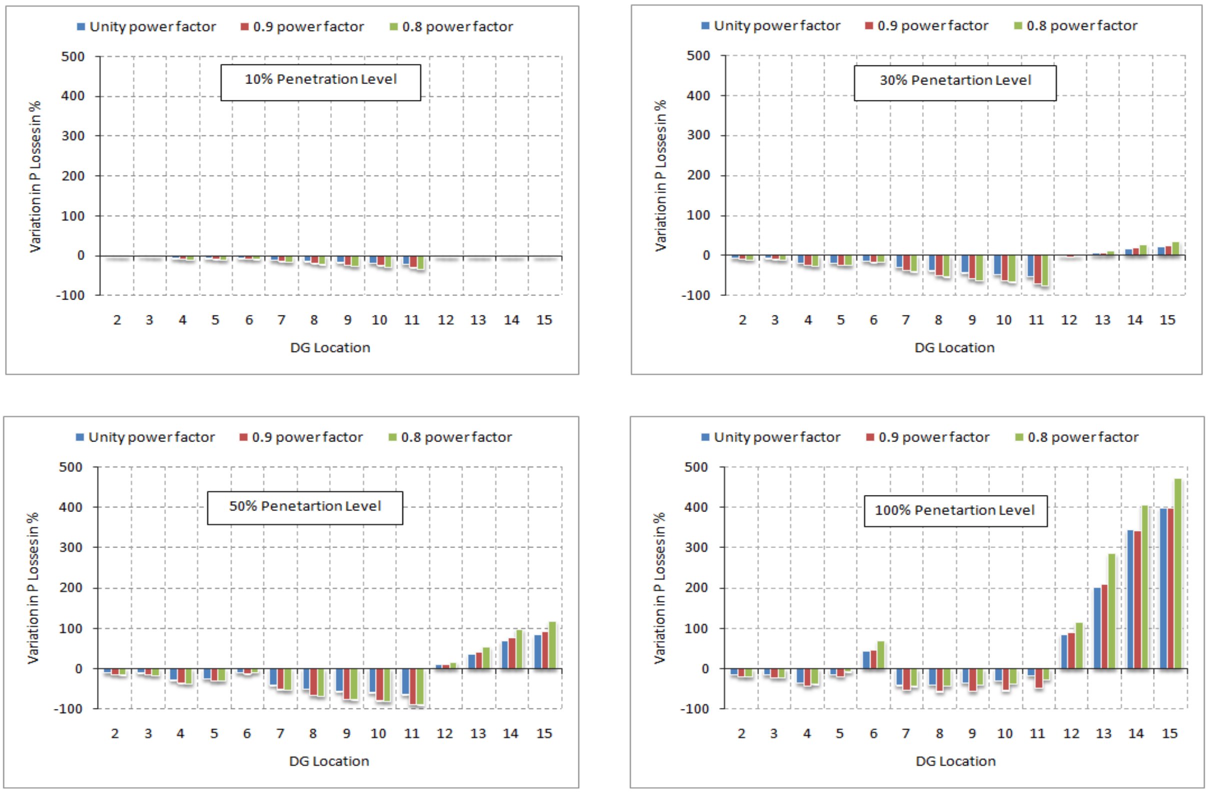

Figure B - 3: Variation of the active power losses in percentage for all penetration levels

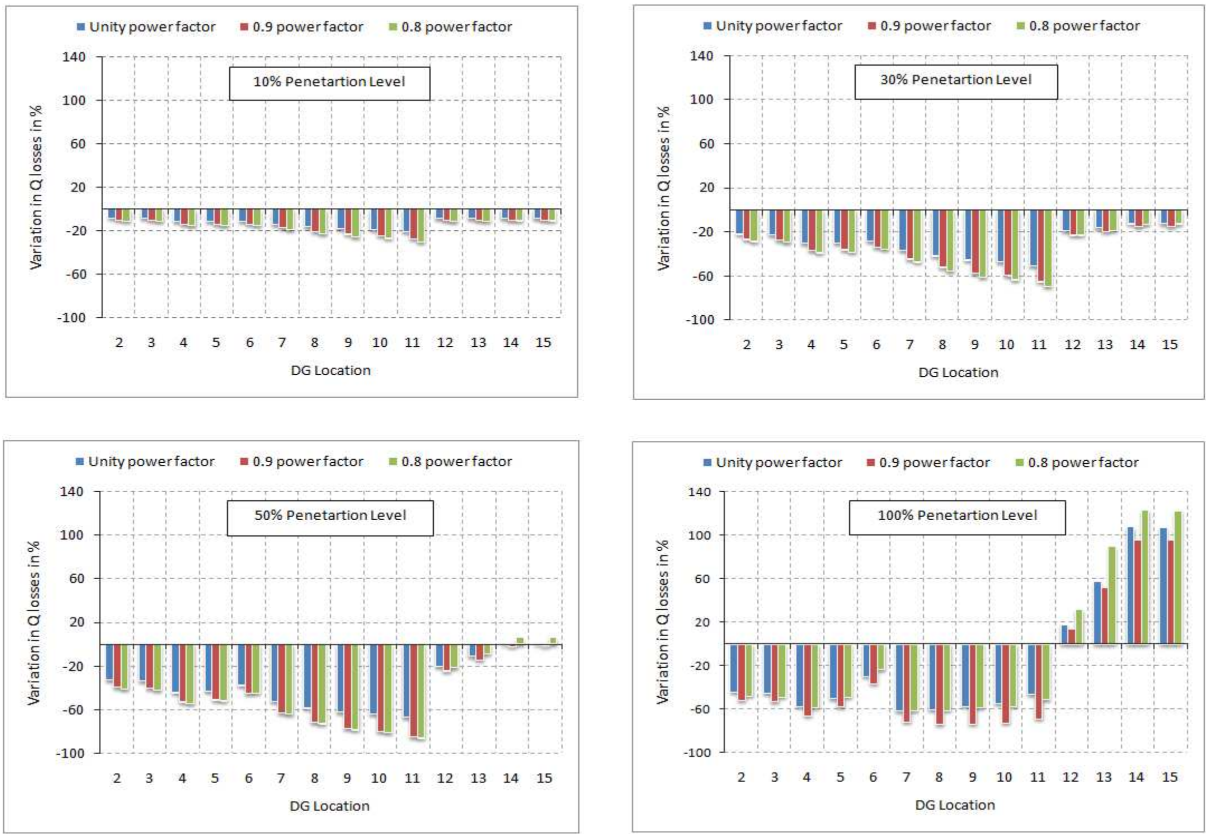

Figure B - 4: Variation of the active power losses in percentage for all penetration levels

APPENDIX C

C.1 Data for 85-Node Distribution Network

Table C - 1: Line and load data of 85-node distribution network [Das et al.,1995]

Line Number	Sending Node (IS)	Receiving Node (IR)	Resistance (Ω)	Reactance (Ω)	P (IR)
1	1	2	0.108	0.075	0.000
2	2	3	0.163	0.112	0.000
3	3	4	0.217	0.149	56.00
4	4	5	0.108	0.074	0.000
5	5	6	0.435	0.298	0.000
6	6	7	0.272	0.186	0.000
7	7	8	1.197	0.820	35.28
8	8	9	0.108	0.074	0.000
9	9	10	0.598	0.410	0.000
10	10	11	0.544	0.373	56.00
11	11	12	0.544	0.373	0.000
12	12	13	0.598	0.410	0.000
13	13	14	0.272	0.186	35.28
14	14	15	0.326	0.223	35.28
15	2	16	0.728	0.302	35.28
16	3	17	0.455	0.189	112.0
17	5	18	0.820	0.340	56.00
18	18	19	0.637	0.264	56.00
19	19	20	0.455	0.189	35.28
20	20	21	0.819	0.340	35.28
21	2	22	1.548	0.642	35.28
22	19	23	0.182	0.075	56.00
23	7	24	0.910	0.378	35.28
24	8	25	0.455	0.189	35.28
25	25	26	0.364	0.151	56.00
26	26	27	0.546	0.226	0.000
27	27	28	0.273	0.113	56.00
28	28	29	0.546	0.226	0.000
29	29	30	0.546	0.226	35.28
30	30	31	0.273	0.113	35.28
31	31	32	0.182	0.075	0.000
32	32	33	0.182	0.075	14.00
33	33	34	0.819	0.340	0.000
34	34	35	0.637	0.264	0.000
35	35	36	0.182	0.075	35.28
36	26	37	0.364	0.151	56.00
37	27	38	1.002	0.416	56.00
38	29	39	0.546	0.226	56.00
39	32	40	0.455	0.189	35.28
40	40	41	1.002	0.416	0.000
41	41	42	0.273	0.113	35.28
42	41	43	0.455	0.189	35.28
43	34	44	1.002	0.416	35.28

Table C-14: Continued

Line Number	Sending Node (IS)	Receiving Node (IR)	Resistance (Ω)	Reactance (Ω)	P (IR)
44	44	45	0.911	0.378	35.28
45	45	46	0.911	0.378	35.28
46	46	47	0.546	0.226	14.00
47	35	48	0.637	0.264	0.000
48	48	49	0.182	0.075	0.000
49	49	50	0.364	0.151	36.28
50	50	51	0.455	0.189	56.00
51	48	52	1.366	0.567	0.000
52	52	53	0.455	0.189	35.28
53	53	54	0.546	0.226	56.00
54	52	55	0.546	0.226	56.00
55	49	56	0.546	0.226	14.00
56	9	57	0.273	0.113	56.00
57	57	58	0.819	0.340	0.000
58	58	59	0.182	0.075	56.00
59	58	60	0.546	0.226	56.00
60	60	61	0.728	0.302	56.00
61	61	62	1.002	0.415	56.00
62	60	63	0.182	0.075	14.00
63	63	64	0.728	0.302	0.000
64	64	65	0.182	0.075	0.000
65	65	66	0.182	0.075	56.00
66	64	67	0.455	0.189	0.000
67	67	68	0.910	0.378	0.000
68	68	69	1.092	0.453	56.00
69	69	70	0.455	0.189	0.000
70	70	71	0.546	0.226	35.28
71	67	72	0.182	0.075	56.00
72	68	73	1.184	0.491	0.000
73	73	74	0.273	0.113	56.00
74	73	75	1.002	0.416	35.28
75	70	76	0.546	0.226	56.00
76	65	77	0.091	0.037	14.00
77	10	78	0.637	0.264	56.00
78	67	79	0.546	0.226	35.28
79	12	80	0.728	0.302	56.00
80	80	81	0.364	0.151	0.000
81	81	82	0.091	0.037	56.00
82	81	83	1.092	0.453	35.28
83	83	84	1.002	0.340	14.00
84	13	85	0.819	0.340	35.28

Power factor of all loads is taken equal to 0.7 lagging

CURRICULUM VITAE

Personal Information

Date of birth: January 11, 1977
Place of birth: Elminia, Egypt
Gender: Male
Marital Status: Married, have 3 kids

Education

School Education

1982-1988 Attended the Taha Elmoshtaka, Primary School, Taha Elaameda, Samlout, Elminia, Egypt

1988-1991 Attended the Middle School, Taha Elaameda, Samlout, Elminia, Egypt

1991-1994 Attended the High School, Elminia City, Elminia, Egypt

University Education

1994 - 1999 Undergraduate student, Department of Electrical Engineering, Faculty of Engineering, Minia University, Egypt

2001 - 2005 Graduate student, Department of Electrical Engineering, Faculty of Engineering, Minia University, Egypt

Work experience

1999 - 2005 Instructor at Department of Electrical Engineering, Faculty of Engineering, Minia University, Egypt

2005 - 2007 Assistant lecturer at Department of Electrical Engineering, Faculty of Engineering, Minia University, Egypt

May 2007 – April 2011, Research assistant at Institute of High Voltage Technology and Electrical Power Systems, Faculty of Electrical Engineering and Information Technology, Technische Universität Braunschweig, Germany

Publications extracted from this thesis

Journal Papers:

1. **Nasser G. A. Hemdan, and Michael Kurrat**, “Loadability Aspects for Medium Voltage Distribution Networks with Integration of Decentralized Generation”, International Journal of Distributed Energy Resources, Vol. 5, no. 3, pp. 187-200 July-September, 2009

2. **Nasser G. A. Hemdan, and Michael Kurrat**,“ Efficient Integration of Distributed Generation for Meeting the Increased Load Demand” International Journal of Electrical Power & Energy Systems, accepted

3. **Nasser G. A. Hemdan, and Michael Kurrat**, “Interconnection of Decentralized Renewable Resources into Distribution Grids: Implications and Planning Aspects” Electric Power Systems Research, Vol. 81, issue 7, pp. 1410–1423, 2011

Conference Papers:

1. **Nasser G. A. Hemdan, and Michael Kurrat**, “Distributed Generation Location and Capacity Effect on Voltage Stability of Distribution Networks”, Annual IEEE Student Paper Conference, AISPC’2008, Aalborg, Demark, pp. 1-5, 15 February, 2008

2. **Nasser G. A. Hemdan, and Michael Kurrat**, “Influence of Distributed Generation on Different Loadability Aspects of Electrical Distribution Systems”, The 20th International Conference and Exhibition on Electricity Distribution, CIRED 2009, Prague 8-11 June, 2009

3. **Nasser G. A. Hemdan, and Michael Kurrat**, “Allocation of Decentralized Generators in Distribution Networks for Enhancing Normal Operation Loadability”, PowerTech 2009 Conference, Innovative ideas toward the Electrical Grid of the Future, Bucharest 28.06 - 02.07, 2009.

4. **Nasser G. A. Hemdan, and Michael Kurrat**, “Can DG Units Provide a New Paradigm for Developing Countries Distribution Networks Enhancement? An Evaluation of Their Technical Benefits”, PESS 2009, Power and Energy Summer Summit, Ilmenau University, Germany, pp. 15 -17, September 2009.

5. **Nasser G. A. Hemdan, and Michael Kurrat**, “Effect of Integration of Distributed Wind Generation into a Real MV Distribution Network: A Case Study Using Measured Wind Data and Simulated Load Profiles”, IEEE General Meeting 2010, Minneapolis, Minnesota, USA, 25-29 July, 2010